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CONSIDERING UNCERTAINTY WHEN PERFORMING ENVIRONMENTAL NOISE MEASUREMENTS

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1 INTRODUCTION

In general, estimates of uncertainties in measured values give an idea of the quality of the measurement. However with environmental noise measurements this is not necessarily the case since the variables affecting the measured levels can often not be controlled. Consequently an appreciation of the uncertainties in results lead rather to a better understanding of the measurement and its potential variability. In some cases, the uncertainty of an environmental noise measurement has to be properly quantified because it is needed to determine whether criteria or allowed tolerances in criteria have been satisfied. When monitoring legally binding boundary noise levels for instance, a high quality measurement may be required to ascertain whether or not a limit has been breached.

Most practitioners engaged in the measurement of environmental noise will be familiar with the basic concepts of microphones and that they are designed to minimise effects induced by meteorological changes in temperature, humidity and pressure. They will be also familiar with the need to use a windshield when measuring outdoors. Measuring conditions are usually chosen for practical reasons that are not related to the limits of the instrumentation. One possible reason for ignoring the relatively small influence of weather on the instrumentation is the realisation that the weather has far greater effect on the propagation or transmission of noise. Obtaining measurement conditions that minimise the effect of changes in wind velocity, air temperature and humidity is by far a greater challenge to the practitioner.

Three elements of any outdoor noise scenario are potentially affected by the weather. These are the noise source, the transmission path and the receiver. Of these the influence of the meteorology on the transmission path is least easy to determine. A recent study [1] into the sources and magnitudes of uncertainty identified the weather and changes in the weather as being one of the most significant influences on measurement uncertainties. This paper is concerned with quantifying these uncertainties, providing an overview of the meteorological mechanisms affecting sound propagation, and providing rules of thumb to give guidance when comprehensive meteorological data are not available when performing environmental noise measurements.

2 MEASUREMENT UNCERTAINTIES AND THE UNCERTAINTY BUDGET

2.1 The Quantification of Environmental Noise Uncertainties

The uncertainties associated with environmental noise measurements need to be quantified in an acceptable and uniform manner. To achieve this two quantities may be specified; the “confidence interval” which is the margin within which the true value being measured can be said to lie, and the “level of confidence” which is a number expressing the degree of confidence in the result. So for example, the noise level is 55dBA ±5 dBA with a confidence of 95%.

2.2 The Uncertainty Budget

To obtain these quantities it is necessary to carry out a procedure that considers each separate contribution to the uncertainty chain, evaluates its contribution and then combines them according to set statistical procedures. Further details of this can be obtained from [2], while [3] provides a good basic primer for all uncertainty determination. The usual procedure adopted is to set up an “uncertainty budget”, often in the form of a speadsheet, in which the various sources of uncertainty, pertinent values and the statistical processes can be listed and combined. In many instances when making environmental noise measurements, the sources and values of uncertainties may not be known or cannot be readily evaluated. In such cases reasonable estimates based on experience can be made, and the importance or otherwise of the decision evaluated alongside those on other known variables. A worked example for an industrial BS4142 measurement is discussed below.

2.3 Reproducibility and Repeatability

An alternative approach to providing an overall statement of uncertainty is to consider declaring values that are statistical maxima based upon sets of practical measurements that encompass the likely statistical variations. Such statements are based on the values of standard deviations of reproducibility and of repeatability of measured environmental noise levels for typical measurement situations. For environmental noise reproducibility measurements are defined as those measurements that encompass the same noise source, measured using the same measurement procedure by different operators using different equipment at different times but not necessarily at different sites. Repeatability measurements cover the same noise source measured using the same method repeated at short intervals by the same operators using the same equipment and at the same site. An investigation set up to provide both repeatability and reproducibility data on uncertainties to be expected from measurements of environmental noise under controlled conditions is described below.

3 METEOROLOGICAL EFFECTS ON THE NOISE SOURCE

Wind strength and direction, which dominate the propagation of noise, may also influence source levels. It is necessary to determine, for instance, whether extra compressors are running, whether cooling louvres are open or closed and particularly on a hot summer evening, whether the factory doors have been left open. Many typical background noise sources are affected by the weather, such as rustling leaves and wet roads. During warm weather the opening of windows and doors may significantly increase the noise breakout from buildings, and noise levels from refrigeration units can increase. The ambient temperature may affect the noise source for a number of reasons, including a change in the sound power of the noise source, change in attenuation characteristics due to a change in the position of enclosures or ventilation requirements, and the operation of additional coolers or fans.

It is therefore good practice to determine the likely effect of changes in the prevailing weather conditions on the noise source, and so ensure that the noise source is operating under conditions relevant to the purpose of the survey. Furthermore one should record and report the prevailing conditions at the time of measurement. Short-term variations in the noise emission will influence the duration of the measurement required to obtain a satisfactory sample. In general, the duration of the measurement should be representative of a single or several complete cycles of operation. Longer-term changes can usually be accounted for by suitable sampling strategies, and should be considered in detail when comparing two measurements, or considering it as single measurement to be representative of a period longer than that actually measured.

Research to apply complex impulse response correlation methods to investigate time-varying sound propagation is under way with the objective of providing researchers, engineers and environmental officers with an improved method for investigating the propagation of noise outdoors [4]. Using this noise source, investigations could be performed in the urban environment without disturbance to residents, or from the presence of high background noise such as from motorways. Comparable noise sources for indoor acoustics are available implementing maximum length sequences.

4 METEOROLOGICAL EFFECTS ON TRANSMISSION

In the case of noise levels measured in the environment, measurement uncertainties can be attributed usually more to factors influencing the source and propagation path rather than the measuring instrumentation. Variation in the propagation conditions introduces the most important and difficult source of uncertainty to many environmental noise measurements. The difficulties arise from:

- Understanding the influence of the various meteorological factors on noise propagation
- Determining the meteorological profile over the propagation path for the duration of the measurement.

However often neither the meteorological data nor its interpretation are generally available and due to the considerable influence of meteorology on sound propagation this fact must be realised and acted upon if significant uncertainties are to be reduced.

Point measurements of meteorology do not suffice to describe precisely how sound intensity will vary with distance. The atmosphere is not vertically homogeneous and in general knowledge of the gradients and fluctuations in the lowest 100 to 200m is necessary to understand sound propagation. In practice, the atmosphere also has horizontal variations. One only needs to stand outside on a windy day to sense gusts, or to cross a road on a hot summer's day to sense temperature variations. Bradley [5] describes the different vertical structures of wind, temperature and precipitation and their influence on sound propagation, and provides some guidance when comprehensive meteorological measurements and sophisticated modelling tools are not available. The more practical and useful of these are rules of thumb are described below.

4.1 Refraction

Noise propagation is controlled by the rate of change of sound speed with altitude, which is mainly a function of the wind vector and temperature. Usually the wind vector has an influence an order of magnitude greater than temperature. Spherical spreading describes how sound diverging from a source is spread over a larger area some distance from the source and so the intensity decreases with distance. Since the area goes up as distance squared, so there is a 10log2^{2} = 6 dB loss for every doubling of distance. However if the sound speed decreases with height due to temperature decreasing upward, causing the sound to bend upward, then sound from a surface source is generally lost upward. If we consider the sound as propagating in the form of rays, the lowest elevation ray emerging horizontally from the source is bent upward to form a shadow zone. For example if the temperature decreases 1° per 100 m of altitude then the lowest ray is at a height of about 10m at a distance of 1km. The sound is focused into a smaller upward cone so the upward sound is on average of more intense.

Conversely if the sound speed increases with height due to temperature increasing upward, the rays bend downward. Increasing the temperature gradient gives greater curvature, which means that stronger temperature gradients will generally give increased sound intensity. For example, if the temperature increases by 1° per 100 m of altitude then the height reached by a ray intersecting the surface at 1km from the source is only 2m.

Wind also affects the local sound speed, usually increasing with height, the rate of increase depending on surface structure and on atmospheric temperature profile. In contrast with temperature gradients, wind speed gradients have a directional effect. With wind speed increasing with height, the sound speed will increase with height in downwind directions, giving rays bending down toward the surface and increasing the intensity of sound. In the upwind direction on the other hand, there will be a shadow zone as the sound rays are bent away from the surface.

The effect of wind speed is generally much greater near the surface than temperature effects. For example, the sound speed gradient at 2m is about 1 m s^{-1} per m height if the wind speed is 2 m s^{-1}, whereas for 1° per 100 m temperature gradient the sound speed gradient is only 0.005 m s^{-1} per m. On the other hand, the sound speed gradient due to wind will generally decrease with height, whereas temperature effects may decrease or increase.

As a guideline for environmental noise measurements, vertical structure needs to be specified at greater heights for greater ranges, and this limit-height increases as range squared. A reasonable rule of thumb to determine the height to which the meteorological data is required is " one unit up for every ten units out", i.e. 100m height for each 1km along the ground from source. The important dependencies on meteorology are essentially confined below 100m but it is generally necessary to measure above 10m. The normal procedure is to obtain the local forecast from the meteorological office or equivalent and to supplement this by on site measurements. The minimum would be the periodic use of a hand held anemometer coupled with an estimate of wind direction. There are of course some rules to follow regarding positioning of the instrumentation to avoid particularly the effect of nearby obstacles, the usual rule of thumb being "10m away for every 1m above ground level". However vertical profile measurements are often simply not available, and we then need to rely on surface point measurements together with visual observations of the environment.

A best guess for daytime conditions when there is some solar heating is the 1°/100m equilibrium cooling rate for a neutral atmosphere. This is known as the daytime convective condition. During the summer night however, the situation can be far more complex since the surface radiates heat through the atmosphere and can cool rapidly if there is not cloud cover. This gives rise to a stable layer in which temperature increases with height. This is known as the night inversion condition, when sound is refracted back towards the ground giving sound enhancement in all directions. If any wind is present, it will result in there being a preferred direction for the enhancement. Turbulent transfer of heat from above will lead to a stable layer that could be several hundreds of meters thick and will generally thicken with time. If there is fog, then the top of the fog layer will be the top of this cool layer. If there is no fog, then a layer of 300m topped by the "daytime temperature at that height minus 3°C" is a reasonable guess. The transition between the daytime convective and night inversion conditions can be estimated by interpolating over the lowest few hundred meters using surface temperatures. Note that these two temperature profiles give very different sound propagation properties.

Wind profiles can have enormous complexity and will dominate over temperature effects in most cases. Ahead of a warm front the winds increase and turn clockwise (veer) with height and to the rear of a cold front the winds increase and turn anti-clockwise (back) with height resulting in a change in wind direction of up to 180deg between the surface and 3000m. This can result in significant changes in the sound speed gradient that causes the sound to return to the ground at several kilometres from the source, often in a different direction to the surface wind. Winds exhibit a lot of more-or-less steady horizontal structure near hills and in valleys, but profiles can contain transient horizontal structure due to gusts and eddies. Furthermore the translation of a large eddy along a propagation path can lead to dramatic fluctuations in measured intensities. Consequently a linear approximation is probably not significantly worse than a logarithmic one in many cases.

4.2 Turbulence

Turbulence is generally stronger near the ground since that is where the airflow interacts with the surface and other obstacles. Scattering by random fluctuations in temperature and wind speed associated with turbulence causes part of the energy in each ray to be diffused into other directions. Scattering is strongly in the forward direction, and a rough rule of thumb is "0.1dB loss per km", so the main effect is in shadow zones, such as behind barriers or hills.

4.3 Precipitation

Precipitation also scatters sound, although this scattering is often neglected due to its transient nature. Precipitation does not vary much vertically, but has huge variations horizontally. Although the scatterers are acoustically hard spheres, their distribution is random and the diffusing effect is similar to that of turbulence. The loss out of the direct rays is proportional to range, and at rainfall rates of around 5 mm/h can be comparable to the effect of turbulence. Scattering by rainfall is dependent on frequency to the fourth power and the angular scattering is quite broad. This suggests that rain losses are only significant over short ranges and at high frequency.

Rainfall and hail can produce wide band noise that can significantly change the general background noise. Snow can significantly affect ground absorption and modify the amount of absorption expected from shrubs and trees. Caution must be exercised when estimating the effect of snow on the ground. The impedance can be influenced by the presence of denser frozen layers within the snow cover and by standing pools of water on the icy surface. The effect of the ground can be significantly altered after precipitation, as the presence of water tends to make the surface acoustically “hard” i.e. less absorbent.

4.4 Atmospheric Absorption

Air is an absorber of sound, the energy being lost to heating the air rather than redistributed into other directions. Due to molecular absorption the air acts as a low pass filter attenuating mid and high frequency sound with increasing distance from source. The absorption losses increase more rapidly with increasing frequency than for scattering, but can be comparable at 100 Hz. Absorption depends on temperature and humidity, both of which vary strongly in the vertical. The absorption characteristic is susceptible to sudden changes e.g. directly after a rain shower. However the higher the humidity and temperature the less the atmospheric absorption, so high frequencies propagate better in fog because of the high humidity.

4.5 Meteorological measurements

Two devices are available that can provide data from the lower atmosphere to assist with the determination of the sound speed profile, potentially in real time. They are remote sensing devices that allow continuous monitoring and hence produce regularly updated profiles. The first device is the SODAR (Sonic Detection and Ranging) [6], which measures wind speed by detecting sound waves that are back scattered from the temperature structure and wind turbulence in the atmosphere. The second device is the LIDAR (Light Detection and Ranging) [7], which detects the weak returns of light energy back scattered by atmospheric aerosols such as dust and smoke, which are agitated by temperature and wind turbulence in the atmosphere. Both use Doppler techniques to determine wind velocity.

More often however when performing environmental noise measurements meteorological data are obtained from sources such as (1) on-site upper air data from radiosonde profiles; (2) meteorological mesoscale model data, forecast hourly, specific profiles are available for defined U.K. sites; (3) on-site surface based data for use in synthetic profiles constructed using boundary layer theory. The latter provide reasonable predictions in downwind enhancement and upwind shadow regions but they are unable to represent elevated wind shear and/or inversions and will never predict focussing conditions. The former requires balloon tracking, either using free pilot balloons or radiosonde balloons with radar reflectors. Tracking can be achieved by radar, by navaid systems such as Loran-C, by radio direction finding or by interfereometry. Of these radar provides the most accurate and most reliable method and is currently used by the meteorological office.

5 METEOROLOGICAL EFFECTS ON INSTRUMENTATION

Technological advances have reduced instrumentation errors and uncertainties to the point where there is a perception that they are negligible when compared with other factors that influence environmental noise measurements. A recent spot check performed by the University of Salford Acoustic Calibration Laboratory on equipment in use by six Environmental Health officers revealed accuracy within 0.6 dB with 95% confidence down to 20 Hertz [8]. Nevertheless, in general one should avoid subjecting instrumentation to the extremes of weather and in particular to sudden changes caused either naturally or artificially by, for instance moving equipment rapidly from a warm interior to a cool exterior.

5.1 Temperature and humidity

The sensitivity of measurement microphones is only slightly affected by the ambient temperature. It is usually not necessary to compensate for this influence. Most sound level meters and their microphones are designed to be used in the temperature range –10°C to +50 °C, with only a ±0.5dB variation in response. However following relatively quick changes in temperature the microphone should be allowed to acclimatise for at least 15 minutes at the ambient conditions to ensure correct operation. In general, humidity has no influence on the sensitivity and frequency response of the microphone. The situations where one should be aware of humidity problems are when sudden changes in temperature and humidity occur, for example, when going from a warm, humid environment to a cool air-conditioned building. Moisture has the effect of attenuating the sensitivity of the microphone and as a side effect, increasing the inherent noise level.

5.2 Atmospheric pressure

Microphones are normally constructed so that any static pressure difference across the diaphragm is eliminated by the use of a static vent tube. If the microphone is subjected to a change in ambient pressure it usually takes some time for the pressure across the diaphragm to be equalised and this can cause erroneous readings. Changes in atmospheric pressure can affect the calibration level of calibration devices such as pistonphones, and corrections will have to be made. Ambient air pressure affects air stiffness and air density, which partially determine the impedance of the cavity behind the diaphragm and therefore the microphone sensitivity. However this effect is small, so a ±10% change in atmospheric pressure will result in a change of less than ±0.2dB.

5.3 Wind effects and wind shields

Sound level meters should always be used with a windshield, not only because they reduce wind noise but also because they cushion the microphone from sharp impacts when measuring in the field. When out of doors, wind induced noise will add to the measured noise level. This can be noise induced directly on the microphone or indirectly by inducing noise in trees for example. The windshield will however act as an acoustic filter and alter the apparent frequency response of the microphone. Some sound level meters include corrective filters that partially equalise this effect. For standard windshields, provided by the manufacturer, it will typically be less than 1dB at any one frequency over the range 10-10k Hz. A windshield of 10cm diameter should suppress wind noise by approximately 12dB or more.

The size of foam windshield is a trade off between a reduction in wind noise and the insertion loss through the foam. Larger windshields will attenuate more wind noise but also more of the acoustic signal. Water loading of foam windshields can further change the overall frequency response of the measuring system depending on the type of windshield and amount of water. When using permanent or semi-permanent installations to measure noise outdoors it is normal to use rain covers and bird spikes to protect the microphone. When using a rain cover it is usually necessary to mount the microphone with the diaphragm facing vertically upwards. Under such conditions and depending on the nature and source of the noise to be measured, due to directional characteristics it may be more appropriate to use to use a pressure microphone instead of the usual free field microphone.

6 EXPERIMENTAL RESULTS

6.1 INDUSTRIAL EXERCISE

The scenario was that complaints had been made about noise, and teams representing different vested interests had been asked to check the levels according to the procedure in BS 4142:1997 [9]. A large factory is located in a valley. Single storey houses are located approximately 400 m across some fields. The factory operates continuously and the external noise sources will remain fairly constant. Vehicle movements are intermittent. The measurements were made approximately 5 m from the noise- sensitive property. Five measurement teams were selected, one to represent a local authority, one an instrument supplier, one a University research team and two acoustic consultants.

Noise metric	**Repeatability**	**Reproducibility**
Ambient level L_{eq}dB(A)	1.9	7.2
Background level L_{90}dB(A)	2.6	12.6

Table 1: Reproducibility and repeatability uncertainties calculated at 95% level of confidence

The reproducibility and repeatability uncertainties were calculated at the 95% level of confidence for the measurement of the ambient and background noise levels, shown in Table 1. The reproducibility uncertainty is far greater than the repeatability uncertainty. This is, in part, attributable to the wide range of weather conditions experienced during the reproducibility measurements, compared to the similar conditions experienced during the repeatability measurements. There is greater uncertainty associated with the measurement of the background level than the ambient level. This is accounted for at least in part by the variation in measurement position between teams, also explaining the large increase between the reproducibility ambient and background levels.

The uncertainty budget is shown Table 2. To generate the uncertainty budget the key factors likely to influence the uncertainty in the measurement were identified and considered individually. Where possible magnitudes of uncertainty are determined either from separate measurements or from data in the literature. Unknown magnitudes were estimated using experience.

The individual running condition of each source could not be monitored without an unrealistic effort. However following discussion with the factory management ±3.0 dB is an overall estimate. Environmental conditions will also affect the production process slightly, for instance more cooling may be required and ±1 dB allowance is made for variability.

The largest effect on transmission will be the weather, and the overall weather conditions were monitored on each occasion using typical automatic weather station equipment. To provide an estimate of the uncertainty associated with the transmission path it is here assumed that all measurements have been carried out downwind, and using guidance from ISO 9613 a figure for uncertainty of ±3dB has been estimated. Measuring under downwind conditions usually produce worst-case conditions at distances of several hundred meters, and so this is a reasonable approach to take for BS 4142. During the two weeks of the measurements there would be small variations in transmission of the order ±0.1dB due to the ground surface changes.

Small changes of up to 10m in receiver position chosen by the teams have been accounted for using inverse square law. Uncertainties in the instrumentation of ±1.9dB were estimated to allow for five different sound level meters were used by five different teams. This practical value has been taken from a Brüel & Kjær guide for a type 1 meter [10]. Although it considers a number of uncertainties, this magnitude is likely to be larger than changes expected over a single measurement period. In this budget we are concerned with the potential influence of variable intermittent background noise on the measured result. Two cases are considered: night-time when the background noise was so low as not to affect the measurement, and daytime when at times the background noise came within 5 dBA of the average measured level. This could raise the measured level by ~1 dB.

Source of Uncertainty	Notes	Value (Half width)	Conversion dBA	Distribution (divisor)	Std Uncert dBA
Source					
Running condition	Normal	3dBA	N/A	Rect(√3)	1.73
Environmental	Small effect	1dBA	N/A	Rect(√3)	0.58
Transmission path					
Weather	400m downwind	3dBA	N/A	Rect(√3)	1.73
Ground reflection	Very small effect	0.1dBA	N/A	Rect(√3)	0.06
Receiver					
Measuring position	Inverse square	10m in 400m	0.22dBA	Rect(√3)	0.13
Instrumentation	Type 1 practical	1.9dBA	N/A	Rect(√3)	1.1
Background (Daytime)	Different positions	1dBA	N/A	Rect(√3)	0.58
Combined uncertainty (Root sum of squares)					**2.8dBA**
Expanded uncertainty (95% confidence)					**5.6dBA**

Table 2: Uncertainty Budget for the industrial exercise

A confidence interval of 2.8dBA with a level of confidence of 95% appears quite reasonable given the practical conditions, and is similar to the reproducibility estimated from the detailed measurements of the five teams. Closer monitoring of the source might produce a reduced value, but this would have required significant efforts. Instrumentation uncertainties dominate the receiver section, although for a single meter the uncertainty budget would be like the ±0.7dB tolerance of a type 1 sound level meter. As usual, the weather is the largest source of uncertainty.

6.2 Correlation of acoustical and meteorological data

Experiments were performed to investigate correlations between the meteorological and propagation data. [11]. These measurements were specifically performed at distances typical to community noise problems. 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 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. Automatic weather stations, SODAR and LIDAR were used to simultaneously collect detailed meteorological information at a number of locations along the propagation path. The measurements detailed here were performed over flat grassland between 1900 and 0500 on the shortest night of the year.
The correlation of the LAeq with vector wind speed is illustrated by figure 1 for receiver distances 112m and to 560m. The number of points in each plot differs due to the effects of background noise on the data selection. The data show a significant correlation for 112m, where 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.

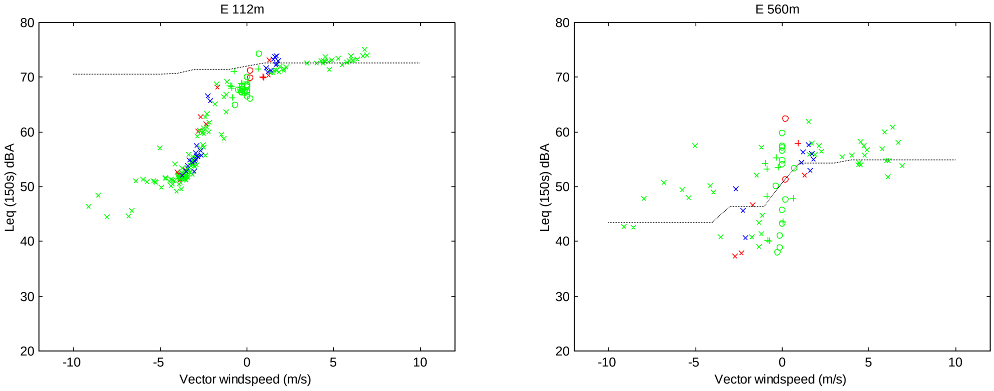

Figure 1: Correlating measured LAeq(150s) with vector wind speed for measurements over grass. Comparisons with CONCAWE (--)

As receiver distance increases the sharp attenuation with negative vector wind speeds is seen to deteriorate illustrated by 560m. It is interesting to compare these data and the depth of the shadow zone for different receiver distances with CONCAWE [12] predictions. For the 112m receiver distance the CONCAWE does not predicted the strong shadow zone. However the predicted shadow zone for the 560m distance is deeper than that measured. This is due to the scattering of sound into the shadow region by turbulence. These measurements illustrate that downwind measurement is normally preferred because the end result is more conservative since the variation is smaller.

6.3 Experiments using LIDAR and RASS SODAR sound speed profiles

There are very few comprehensive field data available with suitably fully characterised ground and atmosphere to allow one to compare measurements with acoustic predictions. This is because it is difficult to measure the range dependent meteorology with sufficient resolution using conventional fixed position sensors. Lately however, sophisticated research tools such as the ground-based LIDAR have been developed which offer the potential of quick remote scanning over distance of up to a few kilometres.
A LIDAR was deployed in a recent field trial at a site with a hilly ground [13]. Wind velocity profiles obtained from the LIDAR were used together temperature profiles obtained from a RASS SODAR to produce range-dependent meteorological profiles. The LIDAR and the SODAR measurements need to be averaged over time period of the order of 10 minutes or more to provide sensible data. A general terrain Parabolic Equation program was subsequently used to predict the sound propagation over the 1km range and over a 5 hour period. The prediction is compared with the simultaneously measured sound propagation data in the 500Hz one-third octave band in figure 2.
The comparisons show that calculations based on the LIDAR data is capable of predicting the correct meteorological influences over this complex ground. The variation in received level is due to the changing meteorological conditions and is seen to increase with source to receiver distance. The measured spread in sound levels of over 20 dB through the 5-hour period is matched by the calculations, indicating that given sufficient detail the full variation in noise level induced by meteorology can be predicted.

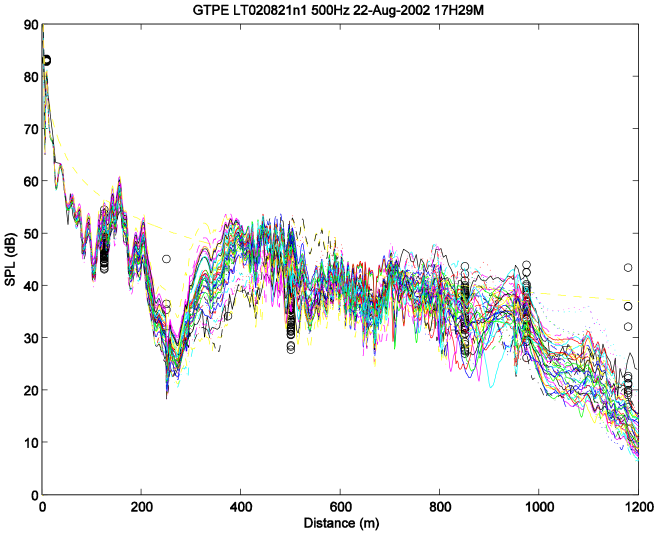

Figure 2: Comparing measured LAeq(150s) sound levels with GTPE predictions using range dependent sound speed profiles derived from Lidar scans over a 5-hour period.

7 DISCUSSION

The standards that the practitioner uses to bring some consistency to the measurement procedure often include guidelines on how to minimise the effects of the weather on measurements. Guidance on environmental noise measurement practice such as that contained in BS4142 has, with successive versions, concentrated on ensuring that the effects of the weather are properly considered. ISO1996 [14, 15] contains a significant amount of detail including an appendix covering meteorological windows and uncertainty.

BS4142 describes a number of precautions that have to be taken to "minimise the influence on the readings from sources of interference " and lists amongst others "wind, passing over the diaphragm…", "heavy rain, falling on the microphone windshield or nearby surfaces….." and it clearly states "use an effective windshield to minimise turbulence at the microphone". On the actual weather conditions under which measurements can be made, it requests that "…the measurement time interval is sufficient to obtain a representative value of the background noise level". It then goes on to explain that "background noise can be significantly affected by meteorological conditions, particularly where the main background noises are remote from the assessment location". It also states that "more than one assessment may be appropriate". Under "Information to be reported" it requires wind speed and direction, presence of conditions likely to lead to temperature inversion (e.g. calm nights with little cloud cover), precipitation and fog. It does not however give specific guidance under what conditions it is most appropriate to measure.

ISO 1996 provides more specific guidance. Part 1 warns "meteorological conditions may influence the received sound level if the distance between source and receiver is about 30m or more". Part 2 goes further and defines a "meteo-window" which is a set of weather conditions during which measurements can be performed with limited and known variation due to weather variation. It goes on to define the conditions for modest conditions which require no monitoring of meteorological conditions and other conditions such as "favourable downwind" which require monitoring or "upwind" conditions that should be avoided. Part 2 also recommends that further guidelines be obtained from ISO 9613-2 [16]. There is also guidance on equipment use and the usual requirements for reporting the weather conditions at the time of the measurement.

Long-term average measurements must be made during periods with different types of weather. If the measurement sample is to be truly representative of a particular season or even a whole year then the weather patterns for the whole of that period must be taken into account. Several attempts have been made to "classify" weather situations [17] and these classifications are useful when determining average weather patterns. They are often accompanied by statistical data on the rate of occurrence and season and time of day of occurrence.

If complaints are made about noise occurring under particular weather situations, then the measurements should be made under those conditions. In the absence of any information on the operation of the noise source that is specific to particular weather conditions it is recommended that measurements be carried out under reasonably stable meteorological conditions. This will improve reproducibility. The most common stable condition for noise measurements occurs under downwind refraction when the propagation falls off uniformly with distance and remains reasonably steady over an extended period. To meet these requirements the wind direction should remain within approximately ± 60° of the direction from the source, with the wind blowing from source to measurement position. The wind speed should be between 2m/s and 3m/s at 3m to 11m above ground and there should be no strong temperature gradients near the ground.

8 CONCLUSIONS

An understanding of the uncertainty in an environmental noise measurement will assist in the application of the data particularly when comparisons are made against established guidelines or criteria. The Uncertainty Budget provides a detailed assessment of all sources of error for any measurement provided the various uncertainties and their magnitudes can be identified. The statistical inter-comparison method is confined to providing an overall assessment for the particular measurement in the field.

To reduce uncertainties in environmental noise measurements it is recommended that weather forecasts be used when planning measurement sessions and meteorological conditions recorded for the duration of the measurement and the observations reported. For long term averages the statistical spread of weather classes should be determined and measurement sessions planned accordingly. Measuring during extreme weather conditions should be avoided and unless specific conditions are required measurements should only be made during favourable propagation conditions.

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