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MODEL FOR SOUND PROPAGATION CONSIDERING METEOROLOGICAL CONDITIONS

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ABSTRACT

For acoustic measurements of more than about 100 m distance, the meteorological effects have an increasing influence with increasing distance. The sound level differences between a reference point close to the passing vehicles and at distances of 100 m to 500 m from motorways and railway tracks were determined. Here the influence of meteorology is described by the effective gradient of the sound velocity c'_{eff} determined from the measured temperature and vector wind speed gradients. It is shown that c'_{eff} and the level difference correlate very well. The correlation can be approximated by an S-Function which is constant for large positive or negative gradients of the effective sound speed. The acoustic influences of downwind and upwind are also shown as a function of frequency.

Keywords: *Sound propagation, Meteorology, Effective sound speed gradient, S-shaped sound level attenuation*

1. INTRODUCTION

For traceable noise measurements from 100 m distance from the sound source, the meteorological conditions must be documented. The very important book "Predicting Outdoor Sound" by Keith Attenborough and Thimothy van Renterghem includes in the first chapter the influence of meteorological conditions on sound propagation [1].
Measured effects of the atmospheric boundary layer on the sound propagation determined during the period from the early evening to the next day are presented in Ref. [2]. In particular, the measured height-dependent temperature and wind speed distributions are compared with the results of log-linear profiles as they are also commonly used for sound propagation calculations.

2. MEASUREMENT AT DIFFERENT LOCATIONS AND CALCULATION OF THE EFFECTIVE SOUND SPEED GRADIENT

Acoustic measurements were made close to the highway or railroad and at a distance of 100 to 500 m from the sound source to determine the influence of meteorological conditions on sound propagation.
In all cases, meteorological measurements were carried out with a tower of at least 10 m, where the wind speed and direction together with the air temperature were recorded continuously at different heights (temperature at 0.3 m, 2 m, 5 m and 10 m, wind speed and direction at 2 m, 5 m and

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10 m). The 2 m and 10 m levels were used to calculate the sound speed gradient.

To combine the effect of the temperature and vector wind speed, the effective sound speed is introduced ([1], [2] and [4]). The effective sound speed is the sum of the height dependent speed of sound c(z) and the component of the horizontal wind speed u(z) between source and receiver. The angle α is between the source-receiver path and the wind vector.

$$c_{eff}(z) = c(z) + u(z)\cos\alpha \tag{1}$$

The refraction of the sound ray is determined primarily by the gradient of the effective sound speed [1]**Fehler! Verweisquelle konnte nicht gefunden werden.**. As a result of the ray acoustics there is a correlation between the refraction of the sound ray and the measured sound level.

With the first term of the Taylor series expressed as finite differences it results in the effective sound speed gradient c'_{eff}.

$$c'_{eff} = \frac{dc_{eff}}{dz} = \frac{c_0}{2T_0}T' + u'\cos\alpha \tag{2}$$

The temperature gradient T' is calculated from the measured temperature difference $T' = (T_{10m} - T_{2m})/8$ and the wind gradient $u' = (u_{10m} - u_{2m})/8$.

2.1 Measurement location: Motorway A2 near Markt Allhau

The first measurement site was located at an almost straight section of the Austrian A2 motorway near Markt Allhau with a reference point at 18 m and a measurement point at 250 m from the central axis of a 4-lane motorway. Figure 1 shows the A-weighted sound level difference $\triangle L_{Aeq,\ 250m} = L_{A,eq,\ 250m} - L_{A,eq,\ 18m}$ and the effective sound speed gradient for one week of measurement period. The sound attenuation *ΔLA,eq* shows a pronounced variation which follows the day/night cycle. This is due to the reversing air temperature gradient. The wind direction is parallel to the motorway and therefore the effect of the wind speed gradient on sound propagation was small in general.

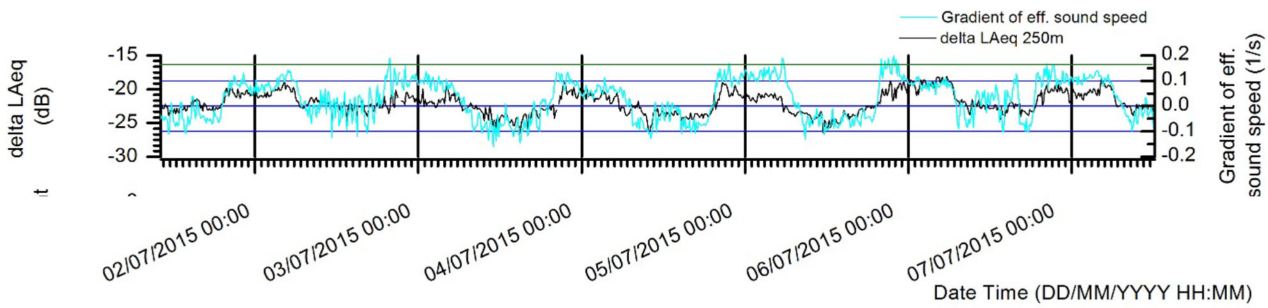

Figure 1: A good correlation between A-weighted sound level difference △LAeq, 250m = LA,eq, 250m – LA,eq, 18m and the effective sound speed gradient (one week of the measurement period) is present

2.2 Measurement location: Railway line near Aderklaa

On the railway line near Aderklaa the sound emissions of the passing trains were measured in a flat region at a reference point at 25 m (a height of 3.5 m above the railway track, 4 m above ground) and at 100 m, 150 m, 250 m and 500 m on both sides of an almost straight track (at a height of at least 4 m above the nearest ground level)

2.3 Measurement location: Motorway A2 near Bad Voeslau

At the motorway (A2) near Bad Voeslau, the sound levels of road traffic noise were measured during a 60-hour period at reference points on both sides of the motorway at a distance of 200 m from the motorway and with a reference point at a distance of 34 m from the motorway. Acoustic and meteorological measurements were averaged over a 5-minute time interval. The wind direction is shown in such a way that 0° represents a favorable sound propagation situation for the south. This measurement period was characterized by strong winds in the first night and day periods with a lack of temperature gradients and in the subsequent night-day period by low winds and strong temperature gradients (see Figure 2).

This resulted in considerable differences in sound levels between north and south whereby the southern measuring point was very favorable in terms of wind and resulted in differences in sound levels of 6 to 8 dB in the first night. On the first day of the test period there was a strong upwind situation for the southern measuring point and a difference in A-weighted sound level between the two measuring points (north and south) of about 10 dB resulted. The second night was characterized by clear sky conditions combined with a strong ground-level inversion. This caused low wind speeds in the measurement profile whereby the wind came from the west and was parallel to the motorway. On the third night, a similar meteorological situation was observed with low sound level differences between the northern and southern measuring points.

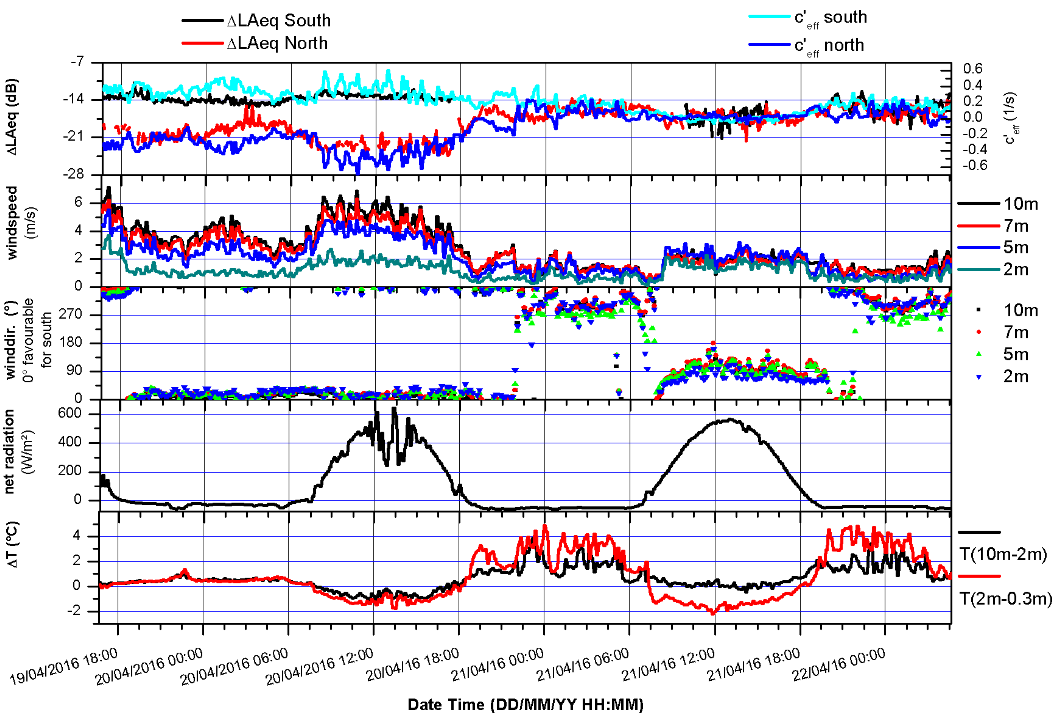

Figure 2: Sound level difference (ΔLA,eq,200m= LA,eq, 200m - LA,eq, 34m) and the effective sound speed gradient on both sides of the motorway in Bad Voeslau with meteorological data [4]

3. MODEL APPROACH FROM THE MEASUREMENTS: S-SHAPED SOUND ATTENUATION

The analysis of the measurement results on sound level difference dependent on the effective sound speed gradient shows that c'_{eff} close to 0 is mainly influenced by the temperature gradient while larger gradients (c'_{eff}) are mainly influenced by the wind gradient. An S-Function describes that the sound level differences are constant for large positive gradients ($c'_{eff} >> 0$) with sound ray refraction downwards and large negative gradients ($c'_{eff} << 0$) with sound ray refraction upwards (included also in Eq. 4).

The sound attenuation ΔL is dependent on the distance d including the unchanged ground effects ΔL(d) and the meteorological effects expressed as ΔL(c´eff).

$$\Delta L(d, c'_{eff}) = \Delta L(d) + \Delta L(c'_{eff}) \qquad (3)$$

The main idea of Salomons and Bakri [3] is to describe the meteorological influence on sound propagation with an empirical S-shaped function describing the effective sound speed gradient, and this will be discussed and applied to our measurement data.

The S-shaped function according to Reference [3] is slightly modified to

$$\boldsymbol{\Delta L(d, c'_{eff}) = U + \frac{H}{e^{b-a\,c'_{eff}}+1}} \qquad (4).$$

The value U is the average lower sound level at large negative gradient, H is the difference between average lower and higher sound levels, b represents the left/right offset and a includes the slope of the S-shaped function.

Figure 3 shows the change of the A-weighted sound level as a function of the effective gradient of the sound velocity. For a better comparison of the different S-curve shapes, the values are related to the sound level attenuation without meteorological influences. This clearly shows a different level increase due to favorable sound propagation (c'eff > 0) and the different level decrease due to unfavorable sound propagation (c'eff < 0).

The acoustic measurements of the train passings in Aderklaa were well evaluable up to 250 m distance. In Bad Voeslau, the sound propagation from a highway was measured and high wind speeds were present which finally led to large gradients.

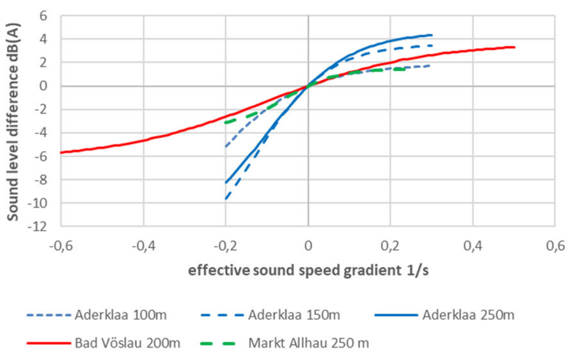

Figure 3: Sound level difference caused by meteorological influences versus the effective sound speed gradient for different measurement situations.

The approximation of the sound level attenuation as a function of c'eff by an S-function shown here was obtained from measured data. On the other hand, it is also very plausible that stronger downwind or upwind leaves the level reduction constantly unchanged.

4. UPWIND AND DOWNWIND SOUND PROPAGATION: FREQUENCY DEPENDENT MEASUREMENT RESULTS

The measurements at the motorway measurement location Bad Voeslau show clear differences in the downwind and upwind situation during the first night (19/20.04.) and also on the following day. In the first night, the level difference measurements were averaged between 8 p.m. and 1 a.m. and on the following day (20.04) between 8 a.m. and 4 p.m. in order to show the level difference between downwind and upwind sound propagation.

The difference in level between the downwind and upwind situation is only due to the wind influence because the temperature gradient at the measuring point in the north and south was the same. The difference between downwind and upwind is mainly seen in the frequency range from 250 to about 5000 Hz.

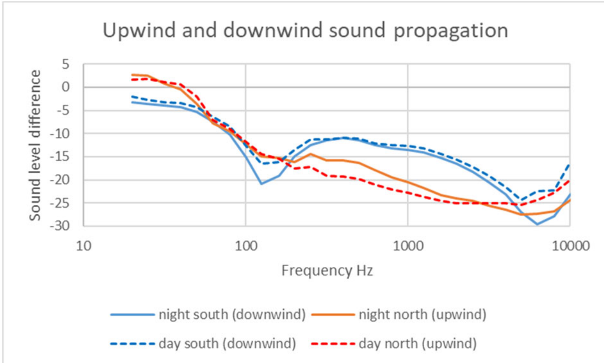

Figure 4: Frequency dependent sound level difference between up- and downwind sound propagation at Bad Voeslau

Figure 4 shows that the level difference is greater than 5 dB at 315 Hz, greater than 7 dB from 630 Hz and in the order of 3 dB at 4000 Hz. The A-weighted level difference is of the order of 7 dB(A) during the night and slightly larger during the day (see Figure 2).

5. REFERENCES

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