Weather-corrected immission levels - comparison of sound propagation models
(Wetterkorrigierter Immissionspegel - Vergleich von Schallausbreitungsmodellen)

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Introduction

The propagation of acoustic waves in the atmosphere is a highly complex issue and depends on many different factors, like e.g. the vertical gradients of wind speed and temperature, the relative humidity in air and local atmospheric turbulences. Weather conditions in favor of sound propagation (e.g. temperature inversion) can cause maximum noise levels, which are not reflected in averaged rating levels. Especially in large distances these effects become evident and can "bypass" already existing noise barriers by bending down sound propagation paths. For practical use most noise assessment methods are based on simplified models and complex physical relations are often incorporated via corresponding correction factors. For instance, in the German guideline for protection from road noise (RLS-90) light downwind conditions and/or temperature inversion are assumed and further meteorological considerations are left out [1]. The preliminary calculation method for environmental noise from roads (VBUS) adds a correction term C_{met} (following the approach in ISO 9613-2) to correct for the influence of meteorology on the long-term sound level. Even though both methods in most cases will overestimate the noise levels, they might fail in more complex situations and in individual weather-dominated scenarios.

Several engineering models in Europe allow considering meteorological aspects. In this manuscript the methods under investigation are the French NMPB-Roads-2008 [2] and the European Harmonoise model [3]. The RLS-90 will serve as "non-meteorological" reference. In the next sections the respective meteorological frameworks are presented in more detail. After that, a simple test scenario is considered and the sound propagation is calculated for different weather profiles to quantitatively compare the results from the different engineering models. We will discuss the necessity for applying weather corrections and whether such corrections can serve e.g. as a supplement to the averaged rating levels.

Meteorology in NMPB-Roads-2008

The NMPB method has been developed to calculate the sound level of roads in greater distance and consider the influence of different meteorological conditions on the sound propagation [2]. The calculation distance validity limit is 800 m perpendicular to the infrastructure with a receiver > 2 m above the ground. Third-octave bands from 100 Hz to 5 kHz are used.

In order to describe the influence of wind and temperature, NMPB starts from the index of refraction $n(d,z)$, which varies with the altitude z and the distance d between source S and receiver R. The deterministic part of $n(d,z)$ (no turbulences) is related to the average sound speed profile $\langle c(z)\rangle$, which in turn depends on average wind and temperature profiles. Here NMPB uses a hybrid profile of logarithmic-linear type since it constitutes a good description of the strong vertical gradient of the sound speed near to the ground and the weaker changes at greater altitudes. Also, in good approximation the sound speed profile is assumed to be time- and range-independent:

$$\langle c(z)\rangle = c_0 + Az + B\ln(1+\frac{z}{z_0}) \qquad (1)$$

z_0 is the roughness parameter of the ground, c_0 = 340 m/s and the coefficients A and B characterize the linear and logarithmic contribution, respectively. One can distinguish between downward-refraction conditions (positive vertical sound speed gradient), for which the sound rays are bent towards the ground (thereby acting favorable for the sound propagation), and upward-refraction conditions (negative vertical sound speed gradient), for which the acoustic energy is shifted towards the sky (thereby being unfavorable for the sound propagation). Since modelling upward-refraction conditions is not trivial, the so-called homogeneous conditions are used instead as an upper bound for the upward-refraction scenario. In this case the propagation of sound occurs in a straight line.

The engineering model behind NMPB is based on point-to-point calculations, i.e. ray-tracing is used to identify the possible propagation trajectories between S and R. For each propagation path the sound level in downward-refraction conditions ($L_{i,F}$) and homogeneous conditions ($L_{i,H}$) has to be calculated so that the long-term sound level for each path can be determined by energetically summing up $L_{i,F}$ and $L_{i,H}$. The weighting of the two types of sound levels is performed according to the meteorological occurrence values for downward-refraction conditions on the site under investigation for the different source-receiver propagation directions (in steps of 20°). The probabilities of occurrence can be obtained via permanent meteorological stations, via own local measurements or by adopting the most suitable tabulated values.

$L_{i,F}$ ($L_{i,H}$) results from subtracting the total attenuation along the propagation path in downward-refraction conditions $A_{i,F}$ (homogeneous conditions $A_{i,H}$) from the source emission power level L_{Awi}. The meteorology is considered explicitly in the attenuation contributions from the ground effect and from diffraction. For the ground effect in downward-refraction conditions height corrections δz_s and δz_r are applied to the heights z_s and z_r of the source and the receiver. This "simulates" the bending of the sound rays above flat ground by considering a curved ground and straight sound rays. Atmospheric turbulence is modelled via an additional height correction δz_T accounting for the coherence loss between direct and reflected rays due to turbulence effects [4]. The need to consider the diffraction effect for a specific path and a specific third-octave median frequency is checked by calculating the path difference δ. If $\delta < -\lambda/20$, the path is considered as direct propagation path. For $\delta > -\lambda/20$ the diffraction part is calculated and the ray bending is taken into account by evaluating δ for the "curved ground", applying Fermat's principle in the vertical plane containing S and R (see Appendix E of [2]).

Meteorology in Harmonoise

Harmonoise has been developed from 2001 to 2004 to provide a first basis for a harmonised European engineering model [3]. The major goal of Harmonoise is to give a more physical description of sound propagation. In particular it wants to avoid errors due to inaccurate assumptions about the influence of ground properties and wants to be able to perform calculations for different weather conditions. Harmonoise is meant to be applicable to an arbitrary terrain profile and uses the Fresnel weighting approach. The engineering model is valid from 25 Hz to 10 kHz and results are given in third-octave bands.

As the French model, Harmonoise calculates the point-to-point attenuation on all relevant paths (2½-dim. approach). For this purpose the source (usually a line source) is represented by point sources situated in the centre of small line segments. The sound level L at the receiver is calculated by considering the geometrical attenuation ΔL_{geo}, the attenuation due to absorption in air ΔL_{air} and the excess attenuation $\Delta L_{\mathrm{excess}}$. The excess attenuation is the most complex part and includes all other physical effects influencing the propagation of sound waves, like refraction, scattering, reflection and diffraction. Also the meteorological influence on the sound propagation is implemented in $\Delta L_{\mathrm{excess}}$. In this context the ground profile plays an important role. It is separated into straight line segments between diffraction edges and – similar to the concept in NMPB – the atmospheric refraction is taken into account by curving the ground while keeping the sound rays straight. More precisely, a conformal coordinate transformation is applied to the ground vertices. This reproduces the effect of refraction in an indirect way: The ground is allowed to bend up/down with a radius of curvature which is determined by the vertical sound speed gradient (with source and receiver staying at the same relative heights as before) and the circular ray paths transform to straight paths, so that the simplified Harmonoise calculation scheme can be applied. This curved ground analogy turns out to be physically realistic and, despite some difficulties [5], more accurate than simply applying correction terms.

The calculation of the atmospheric refraction is based on a linear-logarithmic profile of the effective sound speed in vertical direction of the form given by Eq. (1). The coefficients A and B depend on the specific meteorological parameters of the considered meteorological class and have to be determined either by analyzing $c(z)$ at a number of different heights or by relating the friction velocity u^*, the temperature scale T^* and the Monin-Obukhov length L to A and B via theory. Harmonoise also provides tables with estimates for A and B for various conditions [3]. The default values for A and B are provided for 25 weather classes, i.e. for 25 combinations of wind speed and atmospheric stability (cloud cover). There is of course a trade-off between number of classes and accuracy. The classification of the meteorological classes in [6] showed that ignoring the influence of weather can lead to inaccuracies of up to 6 dB(A) at a distance of 200 m and up to 30 dB(A) at a distance of 1 km. By choosing 25 classes an accuracy of 2 dB is supposed to be achieved for distances between 200 m and 1 km.

Application to a simple test scenario

The area around the Federal Highway Research Institute (BASt) in Bergisch Gladbach has been identified to be well suited to apply the different engineering models. In the south of the building complex, the highway A4 – with an average daily traffic of 74834 vehicles (data from 2016) – is passing by. The air-line distance between the author's office and the highway is about 170 m. From the author's own experience the sound propagation from the highway towards the office buildings depends strongly on the wind direction and weather conditions. In the east and west of the BASt a residential zone with single family houses and an area with high apartment buildings are located, respectively. Both housing zones are separated by the highway through wood land. The area under consideration is shown in Fig. 1. All calculations are performed with *CadnaA* from *Datakustik* and the map was imported from [7].

The model is set up as follows: In general the buildings are 4 m high. For the BASt buildings in the center the heights are set to 10 m and the apartment complex (consisting of seven buildings) in the west is chosen to be 20 m high. These are not the actual heights of the housings but roughly represent the respective dimensions. Since the calculations are only compared to one another, such an approach is sufficient. The only noise source in the model is the highway A4 in the south with a 4 m high sound barrier on both sides (located 4 m from the center of the respective lane). For both lanes the emission for the day is set to $L_{m,E} = 78$ dB(A) (averaged assessment level) in the RLS-90 and to $L'_{WA} = 97.3$ dB(A) in the NMPB (sound power level per unit length). For Harmonoise a traffic noise spectrum with $L'_{WA} = 98.1$ dB(A) as given in the NMPB emission guide is assumed. For comparability, these values are chosen in a way that in close proximity to the source the noise level is equal in all models. The immission at six houses (see labels in Fig. 1) is analyzed at 4 m and 8 m above the ground. It is given as the average value over all exposed house facades. The L_{day} noise map is calculated with a grid of 4 m x 4 m. In the NMPB calculation we probe three meteorological variants: homogeneous conditions in all directions, favorable conditions in northwest direction and favorable conditions in all directions. The Harmonoise model is run once with the wind speed set to zero and once with a wind speed of 10 m/s in northwest direction. The stability class S1 is used (very small cloud coverage) and the temperature and relative humidity are set to 10°C and 70 %, respectively.

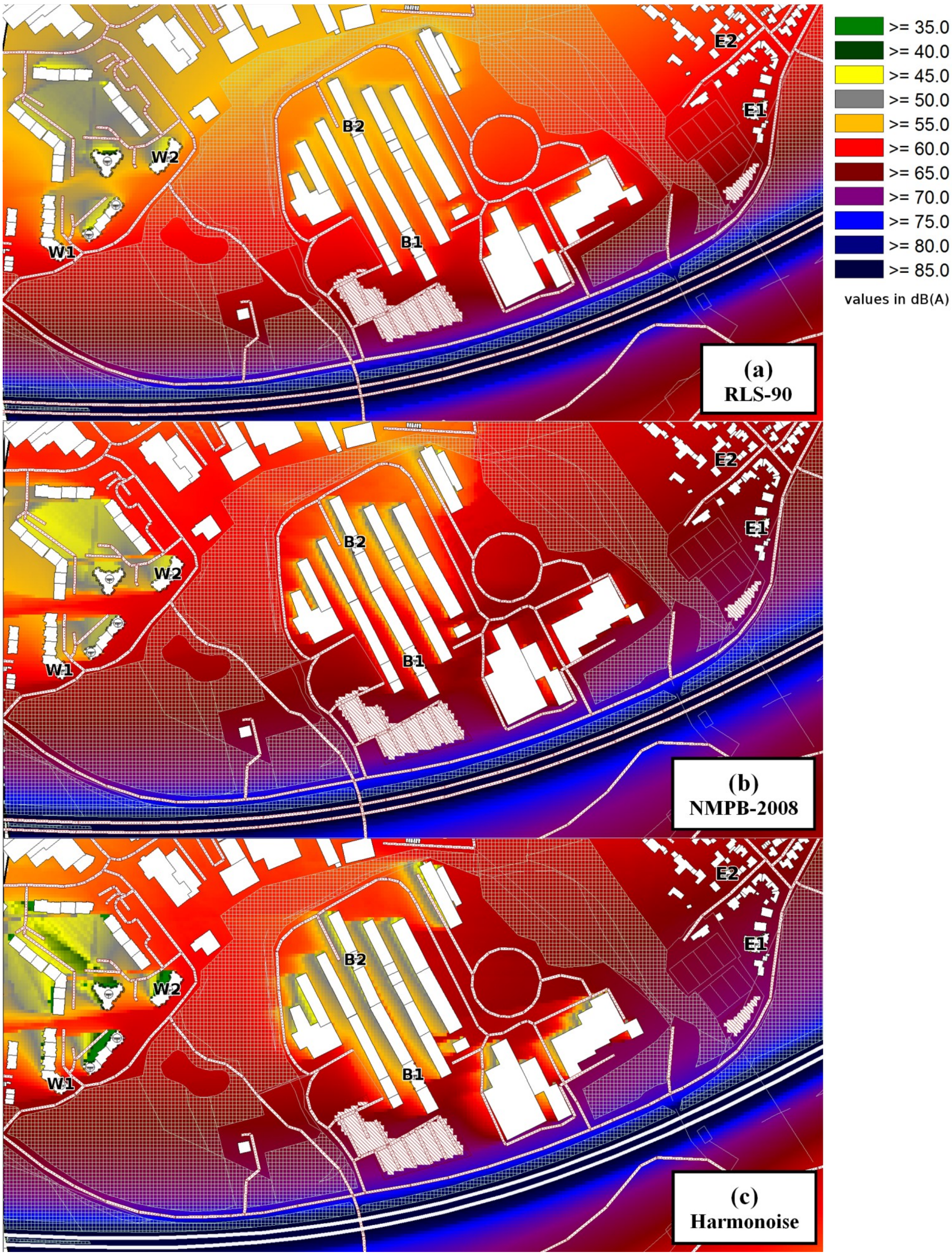

Figure 1: Calculation area and calculated noise grid showing the L_{day} at 8 m height for (a) RLS-90; (b) NMPB-2008 with favorable conditions in all directions and (c) Harmonoise with strong wind in northwest direction. The houses for which the immission is analyzed are marked with W1, W2, B1, B2, E1 and E2. The colour coding is noted next to subfigure (a). All values are given in dB(A).

Table 1: L_{day} at immission points of Fig.1. The 1st value in a cell refers to a height of 8 m, the 2nd value to 4 m. All values in dB(A).

① Immission point	② RLS-90	③ NMPB-2008 homogeneous	④ NMPB favorable	⑤ Harmonoise no wind	⑥ Harmonoise wind towards NW
W1	60 || 59	58 || 58	62 || 63	57 || 57	64 || 65
W2	57 || 57	55 || 54	62 || 61	54 || 52	62 || 62
B1	59 || 57	57 || 56	64 || 62	55 || 55	64 || 62
B2	54 || 50	49 || 49	57 || 49	43 || 41	56 || 52
E1	--- || 60	--- || 59	--- || 65	--- || 57	--- || 69
E2	--- || 58	--- || 52	--- || 61	--- || 41	--- || 62

Results and discussion

Due to the limited space, in Fig. 1 only three noise maps at 8 m height are shown: (a) RLS-90, (b) NMPB with favorable conditions in all directions and (c) Harmonoise with a wind speed of 10 m/s in northwest direction. The influence of the meteorology is very well seen in Fig. 1(b) and (c) in the center corridors between the BASt buildings (B1 and B2) and in the corridors between the high-rise apartment buildings in the west (W1 and W2). Here the favorable propagation of sound leads to locally enhanced noise exposures. On the other hand, one can see that the barrier effect is less pronounced in the RLS-90. Another effect that becomes evident in the calculations including weather is an increase of the L_{day} in farther distance from the highway. Here NMPB and Harmonoise predict up to 5 dB(A) more than RLS-90, despite the presence of the sound barrier. In this case the sound rays "bypass" the barrier because of the downward refraction conditions. The calculations without wind (Harmonoise) and with homogeneous propagation conditions (NMPB) yield significantly quieter noise maps (not shown in Fig. 1) than the RLS-90 and clearly underestimate the degree of exposure. Regarding the computation times, RLS-90 and NMPB handle the test setting reasonably fast (1.5 min and 3 min, respectively), whereas Harmonoise needs more than 30 min. Since our calculation region is relatively small, this raises doubts about the applicability of Harmonoise for large noise maps with a higher number of emission sources.

Let us now have a look at the six immission points in Fig. 1. The corresponding L_{day} values are averaged over all facades of the respective house and summarized in Tab. 1. The results for an immission height of 4 m are also included. It seems that the noise level does not vary much with height (2 dB(A) at most); however, the immission point B2 forms an exception. It is one of the farthest points in the model and, unlike the houses in the east and west, it has no fully screened facade. A maximum difference of 8 dB(A) arises for favorable propagation in NMPB. This shows that considering different immission heights can be important when evaluating weather-dependent situations. The importance of weather effects also becomes obvious when comparing columns 4 and 6 with column 2. In the weather-dominated scenarios nearly all values are significantly higher compared to the RLS-90 results. Of course, the assumptions in "NMPB favorable" and the Harmonoise model with wind are rather unrealistic or rarely occurring, so these scenarios should be taken more as estimation for an upper limit. But since the immission point B1 represents the location of the author's office, the noise level at this point is known to depend strongly on the current meteorology.

Conclusion

Using a simple test scenario, the present manuscript picks up the question to what extent a simplified calculation model without meteorological module is sufficient to evaluate the noise exposure in cases with strong weather influences. The noise level in the chosen scenario is known to be prone to variations depending on the actual wind situation. As expected, the RLS-90 calculation does not represent the worst case scenario, however, when assuming moderate favorable conditions in Harmonoise or NMPB, the German guideline turns out to give a fairly similar picture. Differences in the sound distribution arise especially in corridor-like regions and farther away from the road.

From these first results we for now conclude, that an exact modelling of the meteorology for the purpose of noise mapping is not absolutely essential, but in individual cases authorities should have in mind that such tools exist. Unexpected noise levels can develop for special arrangements of buildings or in greater distance from the emission source and more physical models can then provide important information about why this happens, so that bad planning or inefficient protection measures can be avoided. However, in this context the issue of the meteorological data basis and its accuracy in relation to the desired calculation's accuracy remains problematic. In future investigations we will expand our considerations in this direction and also include the Scandinavian model Nord2000. With measurements at selected immission points (including meteorological parameters) it will be possible to give proper statements about the physical accuracy of the models. Eventually our goal is to obtain a detailed picture about (a) the possibilities to calculate weather-corrected traffic noise immission levels, (b) their validity and applicability and (c) their potential to support noise assessment in complex situations.

References

[1] Bundesminister für Verkehr: Richtlinien für den Lärmschutz an Straßen RLS-90, Ausgabe 1990, Berichtigter Nachdruck (1992).

[2] Sétra report 2009: Noise propagation computation method including meteorological effects (NMPB-2008).

[3] Nota, R., Barelds, R. and van Maercke, D.: Technical Report HAR32TR-040922-DGMR20: Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine tuning (2005).

[4] Dutilleux, G. *et al.*: NMPB-Routes-2008: The Revision of the French Method for Road Traffic Noise Prediction, Acta Acustica united with Acustica 96, 452–462 (2010).

[5] van Maercke, D. *et al.*: Fast and accurate prediction of outdoor noise propagation in the Harmonoise engineering model, InterNoise 2004.

[6] Heimann, D.: Klimatologische Bedingungen der Schallausbreitung, DAGA 2003.

[7] Open Street Map, URL: `www.openstreetmap.org`