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Swedish input data for road traffic noise in CNOSSOS-EU

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According to the Environmental Noise Directive 2002/49/EC (END) the EU member states should map environmental noise in the major cities and report the number of exposed people each 5th year. The noise mapping for the next reporting period shall be done according to a harmonised noise prediction method, CNOSSOS-EU, which is specified in detail in the directive. However, the original document contained some errors and the method has recently been appended with corrections published in an amendment to the directive C(2020)9101. One of the corrections is the default input data for road traffic noise, where the source strengths and speed dependence coefficients of road vehicles have been adjusted to fit the source model and radiation conditions used in CNOSSOS-EU. The prediction model can be adapted to national or regional conditions that differ from the default reference conditions by correction coefficients for the specific national road surfaces. Coefficients for typical Swedish roads for CNOSSOS-EU was reported in 2016, but these were based on the incorrect default source data used in the directive. This paper presents updated road surface corrections for the most common Swedish road surfaces fitted to the recently published adjusted CNOSSOS-EU default road traffic source data. The data could serve as an important input for the next round of noise mapping in Sweden and for similar Nordic countries.

1 Introduction

According to the Environmental Noise Directive 2002/49/EC (END) [1], the member states of the European Union should regularly perform noise mapping of community noise for the major conglomerates in each state. Previously each member state could choose to use existing, national noise prediction methods, but in the next round all member state should use a common harmonized noise prediction model in order to increase the reproducibility and make comparisons between states more equal. The common prediction model for noise assessment was published in 2014. However, the original version of the document contained some mistakes and was amended in 2020 [2], where among other new default values for the road emission source model was introduced. This paper deals with the calculation of spectrum correction terms that could serve as input data for Swedish conditions.

2 The CNOSSOS-EU road traffic noise model

The source model is described in [1]. Two sources are used, rolling noise and propulsion noise, according to equations 1 and 2. The basic model is similar to the Nord2000Road model, but only one source height is used for both the rolling and the propulsion noise sources, and octave bands in the frequency range 63 Hz – 8 kHz is used.

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} \lg\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}(v_m) \tag{1}$$

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m} \left(\frac{v_m - v_{ref}}{v_{ref}}\right) + \Delta L_{WP,i,m}(v_m) \tag{2}$$

where i is the current octave band, and m is the current vehicle category. For a more detailed description of the model and the default coefficients please refer to [1] and [2].

The source coefficients A and B for both the rolling and the propulsion source differ from the corresponding coefficients in the Nord2000Road model not only because they are formulated in octave bands, but they are adapted to different propagation models, and to different traffic noise measurement datasets.

The CNOSSOS-EU model allows for corrections to regional variations in the road surfaces. The sound power level of the rolling noise source, L_{WR}, can be adjusted for variations in sound generation depending on for example road surface roughness in different countries, and the sound power level of the propulsion noise source, L_{WP}, can be adjusted for the effect of an absorbing road surface. The corrections are given in equation 3 and 4.

$$\Delta L_{WR,i,m} = \alpha_{i,m} + \beta_m \lg\left(\frac{v}{v_{ref}}\right) \quad (3)$$

$$\Delta L_{WP,i,m} = \min(\alpha_{i,m}, 0) \quad (4)$$

Without modifying the default coefficients, A and B, for rolling and propulsion noise respectively, only the α and β coefficients can be used to adapt the model to variations in regional conditions.

3 Method to determine road surface spectral correction data

Regional road surface spectral corrections for the CNOSSOS-EU model for Swedish conditions are in this paper estimated based on comparison with the latest update of the Nord2000Road model. In principle the method developed in the Nord2000, Harmonoise and Imagine projects to determine source power has been applied, with the major difference that instead of using measurement data for various road surfaces as input, model results from the Nord2000Road model was used instead. The vehicle sound power data including the spectral corrections for the CNOSSOS-EU model was then calculated, by minimizing the error for the sound exposure levels at the receiver positions.

The procedure used to calculate the spectral corrections for Swedish road surfaces is summarized in these steps.

1. Calculating sound exposure levels for the vehicle categories as a function of speed and road surface using the Nord2000Road model at selected receiver positions at short distances from the road.
2. Calculating spectral corrections for the CNOSSOS-EU model for each category and road surface by minimizing the error between the sound exposure levels calculated with the two different models in the selected receiver positions. This is solved by an iterative algorithm.

3.1 Nord2000Road updated 2015

In [3] the Nord2000 model for road traffic noise was updated and new default source data was proposed for Swedish roads. The report is published in Swedish, but a conference paper summarizing the results can be found in [4]. The update was based on measurements on typical Swedish road surfaces according to NT ACOU 109 [5], with only minor deviations and simplifications. The estimation of the source emission data for the Nord2000Road model was done according to the method described in NT ACOU 116 [6], where the sound power levels in third octave bands of the vehicle categories were calculated based on the sound exposure levels of individual pass-by events measured at four measurement heights.

The Nord200Road considers a number of relevant parameters that influence the source emission such as temperature, road surface type, speed and the use of studded tyres.

Experience from the Nord2000, Harmonoise and the Imagine projects have shown that Swedish road traffic noise levels generally are higher than the corresponding levels in other European member states. The reasons for this have been attributed to the use of road surfaces with larger chip size in order to withstand the use of studded tyres in the wintertime, and also to that the vehicle fleet differs from the average European vehicle fleet.

One major conclusion from the Nord2000Road update in 2015 was that the propulsion noise seems to have been reduced the latest decades. This could be seen for all vehicle types, but the data for category 2 vehicles included too few vehicle passages in order to draw statistically significant conclusions. The reduction in propulsion noise was attributed to the changes in vehicle emission regulations over the last decades, and to the trends of the vehicle fleet toward more energy efficient vehicles. One should bare this in mind when comparing with the noise emission of the CNOSSOS-EU default data.

3.2 Calculation of regional corrections

The relationship between the source sound power level L_W and sound emission level L_E is given by equation 4.

$$L_W = L_E + C(v_{ref}) + 10\,\lg\left(\frac{v}{v_{ref}}\right) \quad (4)$$

where C is a transfer function from the modelled source position to the receiver position, and v_{ref} is the reference speed 50km/h for the transfer function calculation. The frequency dependent transfer function C depend on both. source and receiver positions and the specific propagation model that is implemented in the noise prediction model. This means that the transfer functions are different for the Nord2000Road model and the CNOSSOS-EU model. The transfer functions for the two models for receivers at 7,5 m distance and 0,5 and 4 m heights respectively are shown in figure 1. As the Nord2000Road model uses two source heights there are four transfer functions, one for each source-receiver combination. Note that the Nord2000Road model cover the third octave bands from 25 Hz to 10 kHz, while the CNOSSOS-EU model cover octave bands between 63 Hz and 8 kHz.

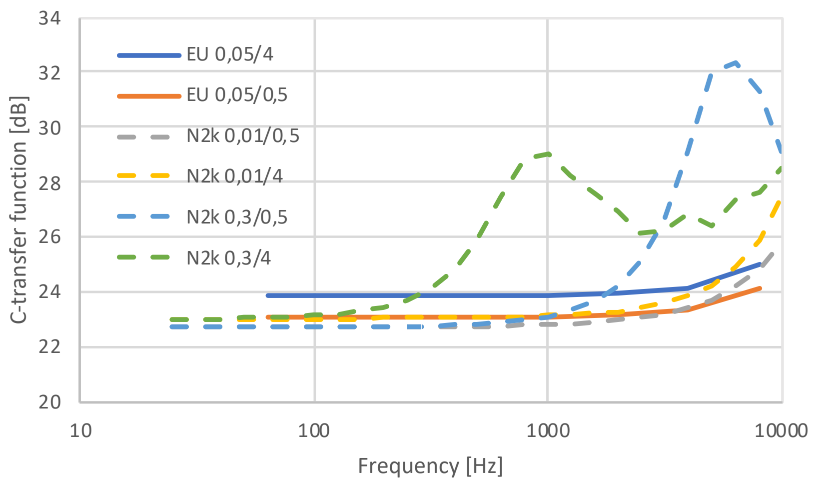

Figure 1. Transfer functions for the CNOSSOS-EU model (EU 0,05/4, EU 0,05/0,5) and the Nord2000Road model (N2k 0,01/0,5, N2k 0,01/4, N2k 0,3/0,5, N2k 0,3/4). The first number in the identifiers is the source height and the second number the receiver height.

Using equation 1, 2, 3 and 4 and the corresponding transfer functions, the sound exposure levels for each vehicle category, road surface type are calculated for the speed range 30 – 120 km/h. The spectrum correction terms can then be calculated by minimization of the average difference of the sound exposure levels at both receiver positions iteratively. Each iteration is divided in two steps. First the spectrum corrections α in each octave band is calculated at the reference speed 70 km/h. Then the speed dependence exponent β is determined in a least square sense for the A-weighted sound exposure levels. The α and β are updated and the process is repeated until the algorithm converges. The initial conditions for the first iteration algorithm are set so that both α and β are zero, which corresponds to the reference road surface.

Other parameters such as temperature, correction for studded tyres or wet road surface are all set to the default reference values.

In this case, two receiver heights were selected at 7,5 m distance from the centre of the road; one at 4 m height and one at 0,5 m height. These positions were selected based on the recommendations in [6].

When solving the minimization problem, the different receiver positions might be given different weights, but in this case both points are weighted equally. Further the calculation of the the speed dependence correction β can be made in different speed ranges. In this case the speed range 70 – 120 km/h was used, since this is the most important for rolling noise corrections. Other results might be obtained if other assumptions are made in the algorithm.

4 Results and proposed spectral correction terms for the CNOSSOS-EU model for Swedish conditions

The most common road surface on high capacity main roads in Sweden is a stone mastic asphalt with a maximum chip size of 16 mm, identified as ABS-16. This road surface type corresponds to SMA16. On roads with lower traffic capacity or in residential areas dense asphalt concrete with smaller chip size is also common, identified as ABT-8 or ABT-11. These road surfaces correspond to DAC-8 or DAC-11 surfaces. These road surface types therefore cover most of the roads that are important for the noise mapping purpose. The calculated regional spectrum correction terms for the main surfaces for Swedish conditions are presented in table 1.

Table 1 Calculated road surface spectral correction terms for common Swedish road surfaces.

Roadsurface	Category	α_{63}	α_{125}	α_{250}	α_{500}	α_{1k}	α_{2k}	α_{4k}	α_{8k}	β
ABS-8 (SMA-8)	1	11,6	2,3	-0,0	1,3	0,1	-0,8	-1,8	-0,9	5,1
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ABS-11 (SMA-11)	1	11,6	2,7	0,7	2,1	0,9	-0,1	-1,2	-0,5	5,1
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ABS-16 (SMA-16)	1	11,7	3,4	1,9	3,3	2,1	1,2	-0,3	0,8	5,1
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ABT-8 (DAC-8)	1	11,5	2,0	-0,2	0,7	-0,5	-1,3	-2,2	-1,2	5,0
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ABT-11 (DAC-11)	1	11,6	2,4	0,1	1,4	0,3	-0,6	-1,6	-0,8	5,1
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
ABT-16 (DAC-16)	1	11,7	3,1	1,3	2,7	1,5	0,6	-0,7	-0,0	5,1
	2	-0,3	-0,2	6,0	2,3	1,0	0,3	-1,3	-0,5	11,9
	3	8,3	-0,6	1,5	0,3	-0,7	-1,1	-4,4	-2,1	14,7
	4a/4b	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

The results show that rather large corrections are needed for α in octave band 63 Hz is required for especially category 1 vehicles (light vehicles), which corresponds to the low frequency noise. Additionally, large corrections of the speed dependence β of category 2 (medium heavy vehicles) and category 3 (heavy vehicles) are needed. This might, at least partly, be explained by the difference in speed dependence of the propulsion noise for the average European fleet used as default in the CNOSSOS-EU model, and the dataset used for the Nord2000Road model.

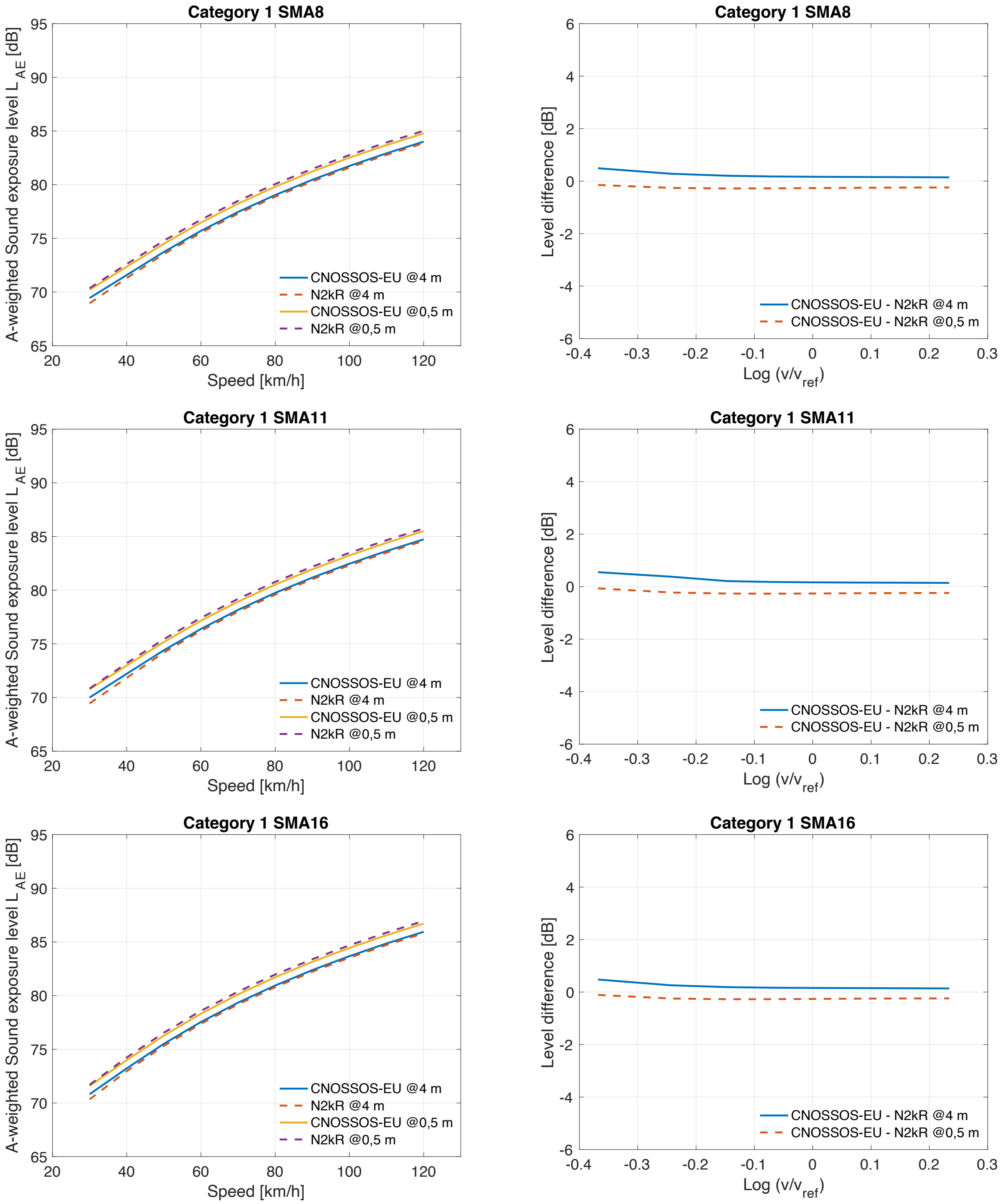

Figure 2. Calculated results for category 1 on SMA (ABS) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions.

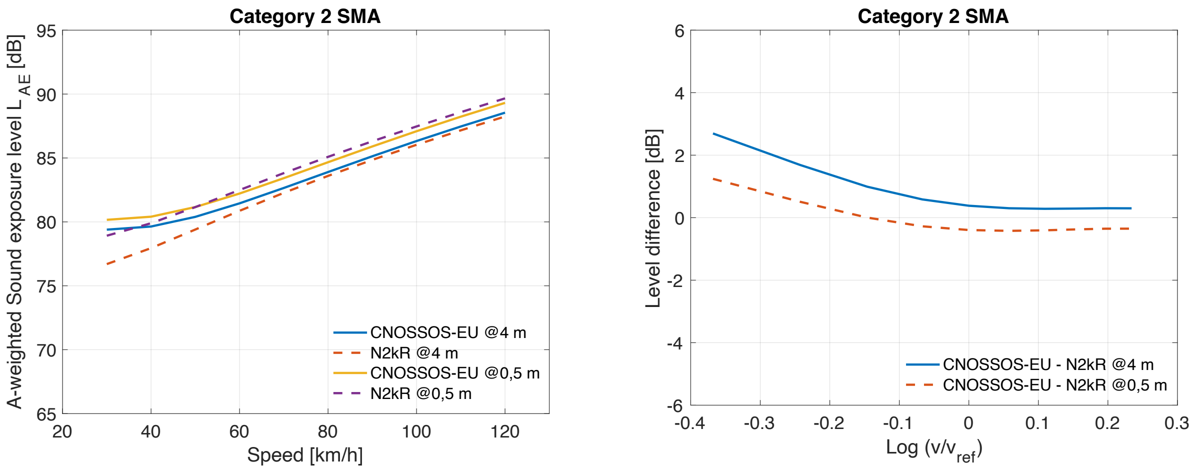

Figure 4. Calculated results for category 2 on SMA (ABS) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions.

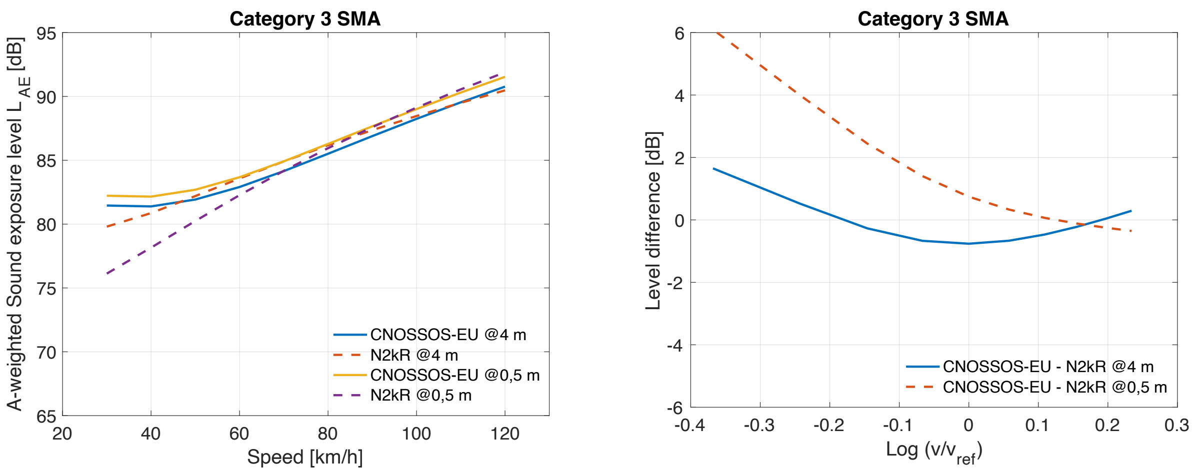

Figure 5. Calculated results for category 3 on SMA (ABS) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions.

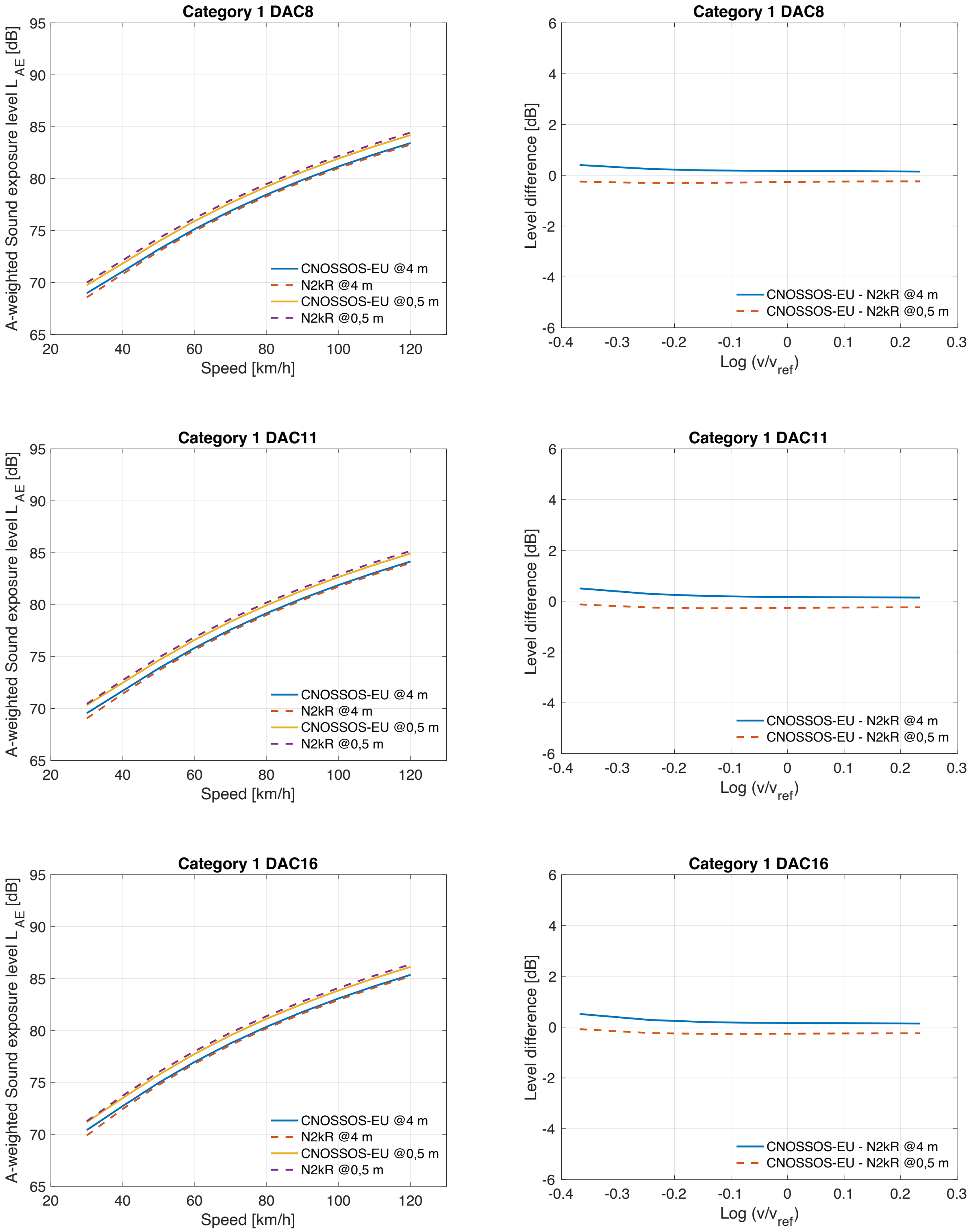

Figure 6. Calculated results for category 1 on DAC (ABT) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions.

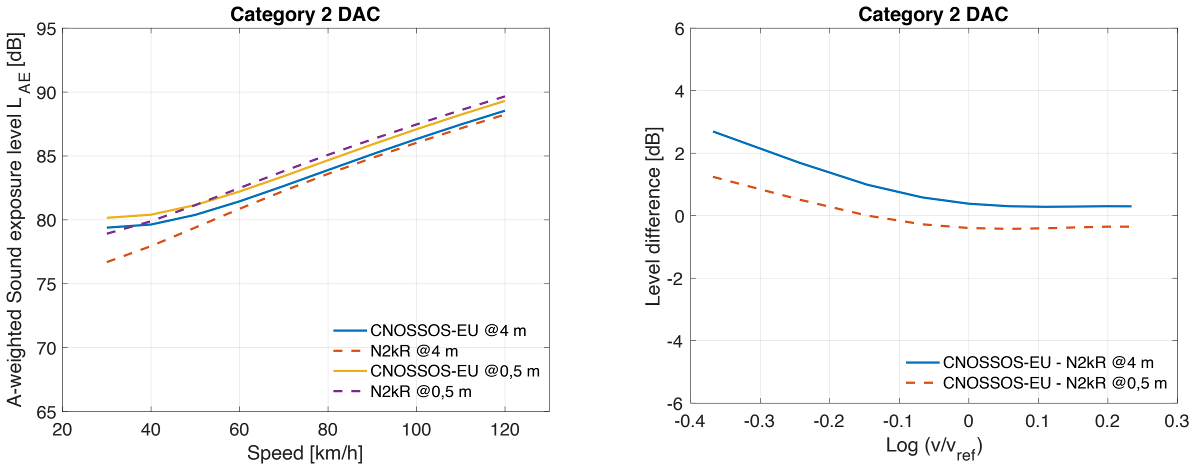

Figure 7. Calculated results for category 2 on DAC (ABT) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions.

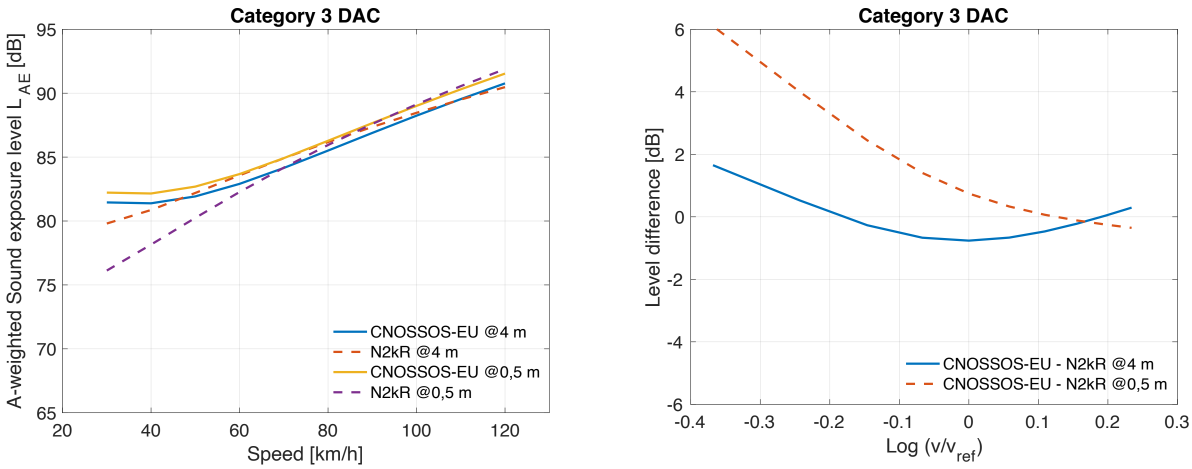

Figure 8. Calculated results for category 3 on DAC (ABT) surfaces. Left: Calculated A-weighted sound exposure levels as function of speed at 0,5 m and 4 m height, 7,5 m distance, from the CNOSSOS-EU model with corrections according to table 1, and the Nord2000Road model updated 2015. Right: Level difference as function of speed with logarithmic axis between CNOSSOS-EU with corrections according to table 1 and the Nord2000Road mode at the two receiver positions

Because of the differences in the propagation and source models it is not possible to find full agreement between the CNOSSOS-EU and Nord2000Road at various receiver heights.

The results show that for category 2 and 3, the same corrections are made for each road surface. The reason for this is that the Nord2000Road model, which is used to generate the target exposure levels for the calculations, does only correct for the road surface for the category 1 vehicles. Thus, the Nord2000Road calculations gives the same noise emissions for a specific road surface independent of the maximum chip size for category 2 and category 3 vehicles. However, other parameters such as temperature corrections depend on the road surface type, also for these categories.

Additionally, the results show discrepancies up to 6 dB at low speeds for the category 2 and 3 vehicles. One reason could be the different speed dependencies for the propulsion noise and the rolling noise. In the latest update of the Nord2000Road model, basic data for the propulsion noise was lowered by approximately 3 dB. At low speeds for heavy and medium heavy vehicles the propulsion noise is dominating, while the rolling noise dominates at high speeds, above 70 km/h, where a better adaptation was possible.

5 Discussion and conclusions

The results presented in this paper was based on adaptation to the Nord2000Road model. Unfortunately, no new additional measurements have been done since the latest update was made in 2015. The results and the quality of the spectrum corrections depend on the accuracy of the Nord2000Road model.

Since the calculations of the spectrum correction terms α and β are based on the Nord2000Road model the corrections for the road surface mainly affects the category 1 vehicles. For category 2 and 3 vehicles, the correction terms can mainly be seen as an adaptation to the Swedish vehicle fleet, and the correction are in principle the same independent on road surface. This is an effect of how the Nord2000Road model handle road surface corrections.

If the default A and B coefficients of the CNOSSOS-EU model also was updated to better fit the Swedish dataset, other spectrum correction coefficients α and β could be established, probably resulting in better agreement especially at low speeds for category 2 and 3 vehicles.

6 Acknowledgement

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