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Uncertainty in Industrial Noise Calculations with Nordic Prediction Method

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In noise calculation projects, the uncertainty of both the emission levels and of sound propagation must be taken into account. Calculation standards such as General Prediction Method (GPM) are mostly conservative, based on light downwind or inverse temperature conditions, reducing the risk of underestimating results. However, severe calculation errors can nonetheless occur due to general uncertainty and the limitations of the method. Uncertainty of emission levels and propagation can be quantified to a certain degree and combined to an overall uncertainty. Based on 4 existing industrial projects with several statistically independent noise sources, uncertainty when using GPM for industrial noise purposes was examined and set into relation to the implicitly used conservative conditions. Standard deviations for noise sources and propagation were visualized on a map. The results were used for identifying sources which contribute most to overall uncertainty at receiver positions, in order to focus on the correctness of these sources.

1 Introduction

When assessing noise from industrial sources with ray-based calculations, a consultant typically calculates based on various assumptions, and the results inevitably contain a certain degree of uncertainty. A few dB of deviation from reality might be acceptable – if it's in the right direction, i.e. if it doesn't lead to the situation where a noise indicator at a receiver is calculated to be satisfactory, while noise levels in reality are exceeded. In order to account for this, most calculation methods – including E*nvironmental noise from industrial plants: General prediction method* (GPM) [1] and *ISO 9613-2* [2] – imply an assumption of a slight downwind or of an inverse temperature gradient. However, the standard deviation for the sound power levels of noise sources in the models is often large and needs to be accounted for, too.

This paper shows an approach to visualize uncertainty (standard deviations of sources and propagation) on maps basically in the same way as noise levels are shown, which in itself is an established technique. The focus of the paper is to show a practical use of the visualization techniques, i.e. to identify problematic areas, so that the consultant can focus on the correctness of those factors that matter for the uncertainty of the overall result.

2 Uncertainty to be considered

In a typical outdoor industrial noise project (e.g. an industrial facility or a harbour in close distance to dwellings), both source and propagation uncertainty can lead to a deviation between reality and calculated results.

2.1 Source uncertainty

Typically, the sound power level for industrial projects is assessed by measurements in the field based on standards like ISO 3744/3746 [3] and can be supplemented by immission measurement methods like the Norwegian M-290 [4]. The circumstances for the measurements can vary a lot, as can the uncertainty. For existing industrial plants, ideal measurement conditions are rather the exception than the norm.

Measurement uncertainty can be of both random and systematic nature. Random errors, e.g. caused by source variations, will always occur, and can e.g. be minimized by repeating the measurement often enough. Systematic errors can e.g. be wrong assumptions on ground hardness or on the distance to the actual source that is measured, wrong (not realistic) settings on machinery, not detected background noise, wrong calibration, wrong assumptions on source directivity, near-field correction or on a machine's active time. Systematic errors have in common that they typically aren't detected and thus not minimized.

ISO 3746 provides typical values for uncertainties of what the standard calls σ_{omc} (standard deviation for operating and mounting conditions) and σ_{R0} (standard deviation due to reproducibility of the method). Typical values when measuring according to the standard are:

- σ_{omc}: between ca. 0,5 dB for well carried-out measurements and small variations in L_w, and 4 dB for extreme cases with varying noise
- σ_{R0}: upper values around 3-4 dB depending on tonality (for accuracy grade 3, survey grade)

According to [3], equation (1) is used for the overall measurement uncertainty σ_{tot}.

$$\sigma_{\mathrm{tot}} = \sqrt{\sigma_{\mathrm{R0}}^2 + \sigma_{\mathrm{omc}}^2} \tag{1}$$

With the values given above, a measurement carried out according to the standard should result in an overall source standard deviation between ca. 3 and 6 dB. Considering the non-ideal conditions in the field, an overall standard deviation of no less than 6 dB for the source should be likely.

In many cases, industrial facilities, harbours etc. consist of many statistically independent noise sources. In this paper, it is assumed that they are all statistically independent. Overall source standard deviation for them is according to [5] calculated with equation (2).

$$\sigma_{\mathrm{src}} = \frac{\sqrt{\sum_j \left(\sigma_j * 10^{(0,1*L_j)}\right)^2}}{\sum_j \left(10^{(0,1*L_j)}\right)} \tag{2}$$

where L_j is a receiver level with contribution from only one source j, and σ_j is the affiliated standard deviation.

2.2 Propagation uncertainty and uncertainty due to the calculation method

Calculation methods used in the scope of assessing noise around industrial facilities are typically ray-based engineer's methods, as opposed to more exact wave-based methods. Ray-based methods are usually fast, robust and approximate reality close enough for many use cases.

Noise immission is usually assessed as a long-term (e.g. yearly) average, eliminating short-term variations. However, assumptions one has to make regarding ground hardness, average wind directions and other factors, influence (along with the uncertainty of the method itself) the propagation uncertainty. Generally speaking, the further away from the source a receiver is, the larger the uncertainty.

In Norway, GPM[1] is typically used. Calculations with the method, as with many other methods, are limited to moderate downwind conditions or slight temperature inversion. GPM states an order of magnitude of expected standard deviation between 1 and 3 dB for "groups of broadband sources at distances less than 500 m, with high values at immission points approximately 2 m above the ground (…)".

ISO 9613-2, another often used calculations standard, gives an "estimated accuracy" of ± 3 dB for average source- and receiver heights between 0 and 5 m, and distances below 1000 m. the accuracy is meant to be in the absence of screening or reflection, and is limited to situations with moderate downwind conditions.

[1] General Prediction Method

In [5], it is recommended using equation (3) to approximate propagation uncertainty.

$$\sigma_{\mathrm{prop}} = k * \lg\left(\frac{d}{d_0}\right) \; for\; d > d_0 \quad (3)$$

with d_0 = 10 m and k = 2 dB

The equation provides a simple approach for estimating propagation uncertainty as a function of the distance based from the source, and gives results which are roughly within what GPM and ISO 9613-2 suggest. Propagation uncertainty from one source to one receiver is then calculated 2 dB in 100 m distance and 4 dB in 1000 m distance.

Uncertainty due to how calculation methods handle reflection, screening, meteorology etc. come in addition and can have a large impact. For instance, in GPM, lateral screening around more than one edge is e.g. not defined, which can lead to a severe underestimation of the calculated value at the receiver. More modern methods like Harmonoise offer parameters like meteorological stability classes, which are not covered in this paper and its focus on GPM.

2.3 Overall uncertainty

Overall standard deviation – consisting of source and propagation uncertainty – is calculated with equation (4).

$$\sigma_{\mathrm{tot}} = \sqrt{\sigma_{\mathrm{src}}^2 + \sigma_{\mathrm{pro}}^2} \quad (4)$$

where σ_{src} is the standard deviation of the source and σ_{pro} of the propagation.

The total standard deviation can, if desired, be used to calculate a confidence interval to evaluate the certainty of not-exceeded levels. In the case of the upper level of a 95% confidence interval, equation (5) is used.

$$L_{95\%} = L + 1{,}645 * \sigma_{\mathrm{tot}} \quad (5)$$

3 Source uncertainty: constructed test cases

In a series of simple, constructed test cases, source standard deviation according to equation (2) has been calculated with a varying number of statistically independent sources with the same sound power levels, where each source has a standard deviation of 6 dB. The results are visualized in Figure 1. As expected, overall standard deviation decreases with an increased number of sources. With 100 sources, it is reduced to 0,6 dB for distances large in comparison to the distance between sources.

However, the result will differ vastly when just few sources have dominant levels. Figure 2 shows the same situation as Figure 1, but with one source having a dominant sound power level. All sources are assumed to have σ = 6 dB. Overall source standard deviation is dominated by the one source and will be just below 6 dB even for a larger number of sources.

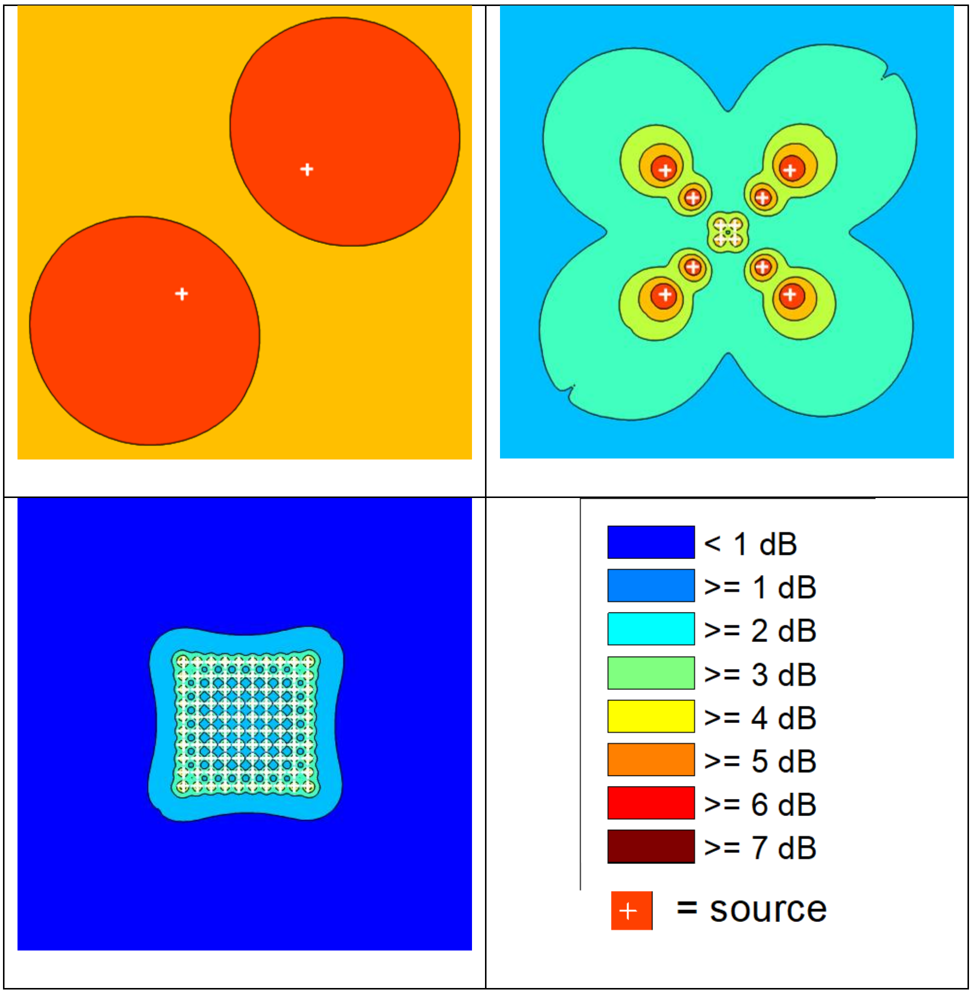

Figure 1: Standard deviation σ from source uncertainty for 2 (upper-left), 12 (upper-right) and 100 (lower-left) sources, where each source has the same sound power level and the same σ = 6 dB

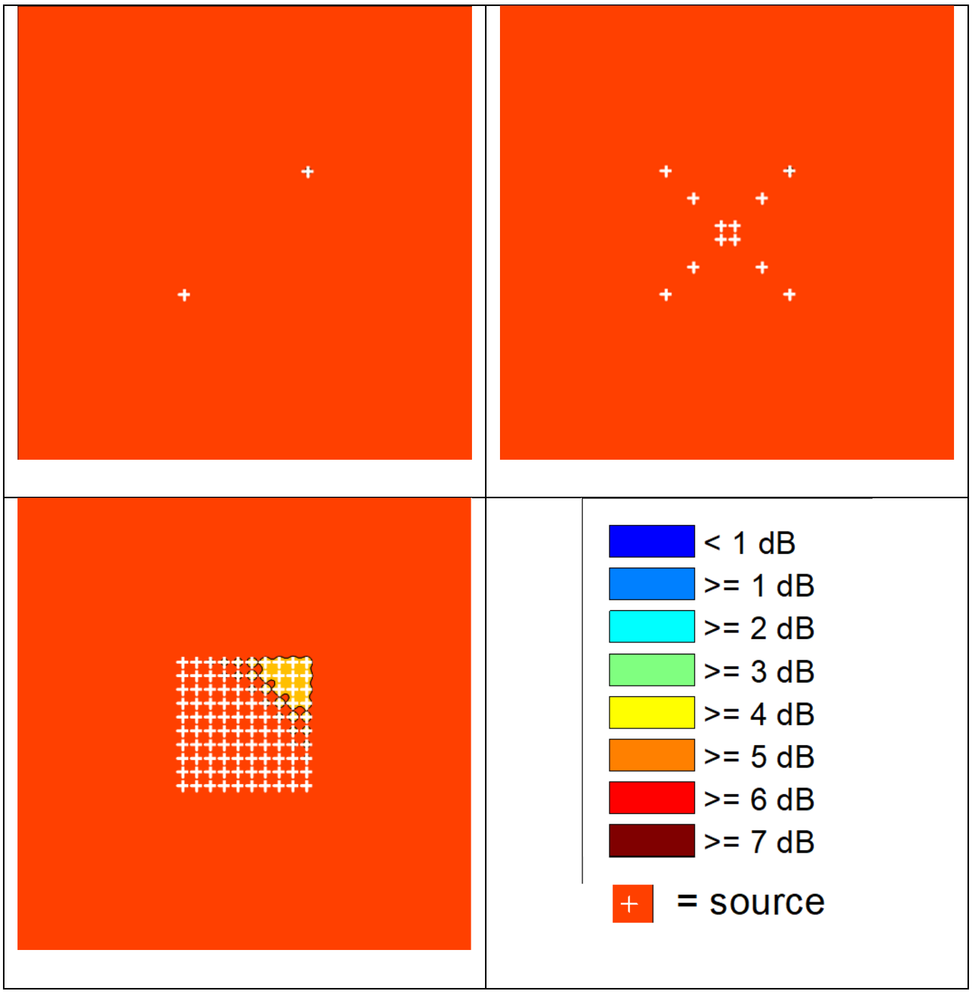

Figure 2: Standard deviation σ from source uncertainty for 2 (upper-left), 12 (upper-right) and 100 (lower-left) sources, where each source has σ = 6 dB. One source has a dominating sound power level.

4 Source uncertainty: practical test cases

In a practical scenario, the situation will most likely be somewhere in between the extreme source uncertainty test cases presented above. Some sources will be dominating, but not to an extent as above.

Source uncertainty has been calculated for 4 actual projects in the scope of this paper. Two of them are harbours, and two are industrial plants. Sound power levels for the projects were assessed by different acousticians. σ is conservatively assumed to be 6 dB for each source.

The results for source standard deviation σ in the whole project area, calculated with equation (2), is shown in Figure 3, Figure 4, Figure 5 and Figure 6 in the form of standard deviation maps. These offer valuable insight in expected uncertainty.

In most cases, overall source standard deviation at receivers is calculated to be around 2-3 dB. One case with considerably higher σ is shown in Figure 4. Interestingly, from the 4 presented cases this is the one with the highest number of statistically independent sources, which theoretically could help reduce source uncertainty. However, since several areas in the project are dominated by one or few sources (other sources are screened or have a negligible L_w), σ is almost 6 dB at some houses. Based on the resulting maps, it is easy to identify areas in which the calculated level is less certain than in others. The consultant can focus on the sources responsible for the uncertainty at the receiver position, and thus reduce uncertainty at these "weak spots".

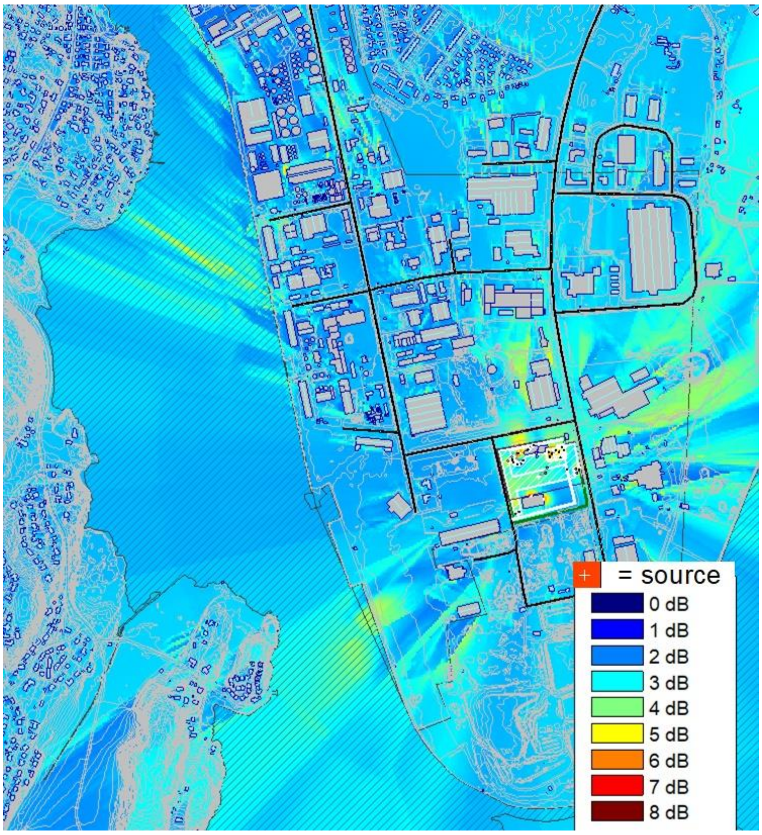

Figure 3: Calculated overall source standard deviation σ in dB for an industrial facility with receivers (houses) in rel. far away (ca. 1 km). Number of active sources: 30

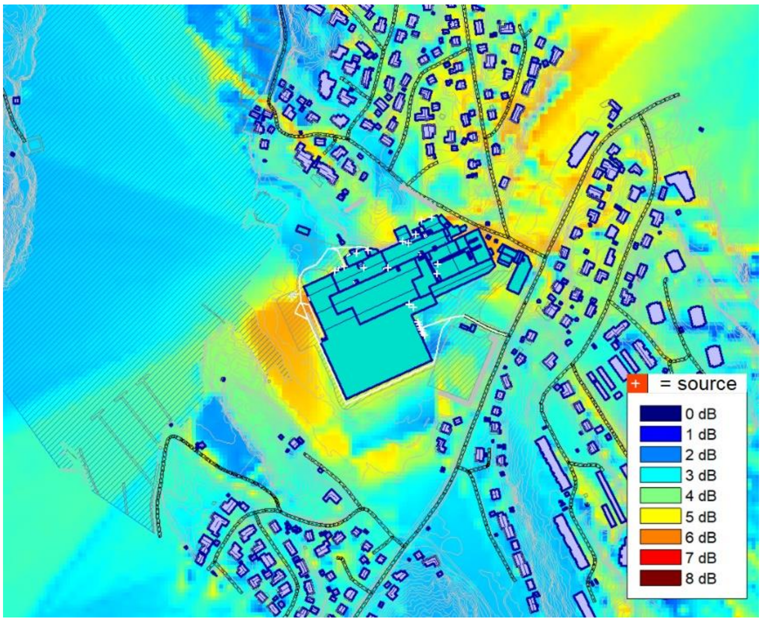

Figure 4: Calculated overall source standard deviation σ in dB for an industrial facility with receivers (houses) in close proximity (< 100 m). Number of active sources: 40

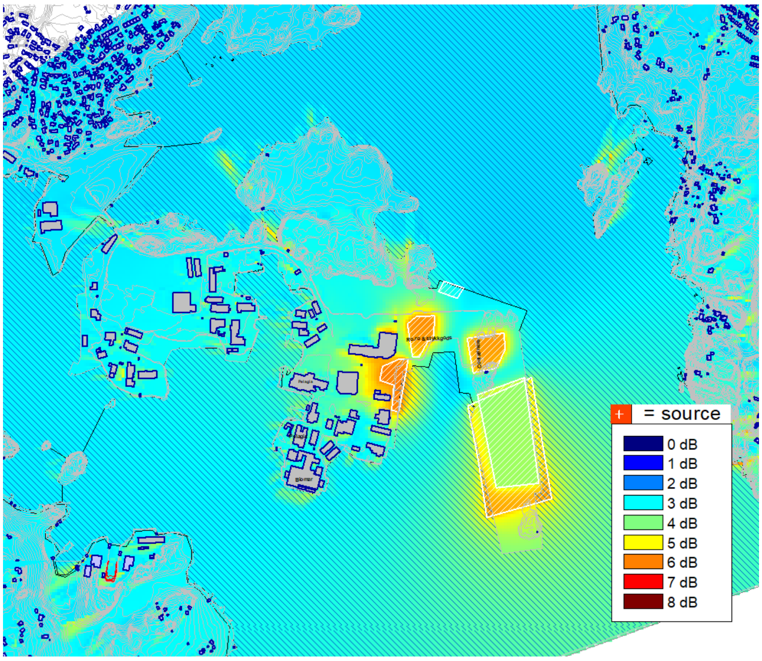

Figure 5: Calculated overall source standard deviation σ in dB for a harbour with receivers (houses) in rel. far away (ca. 500 m). Number of active sources: 6

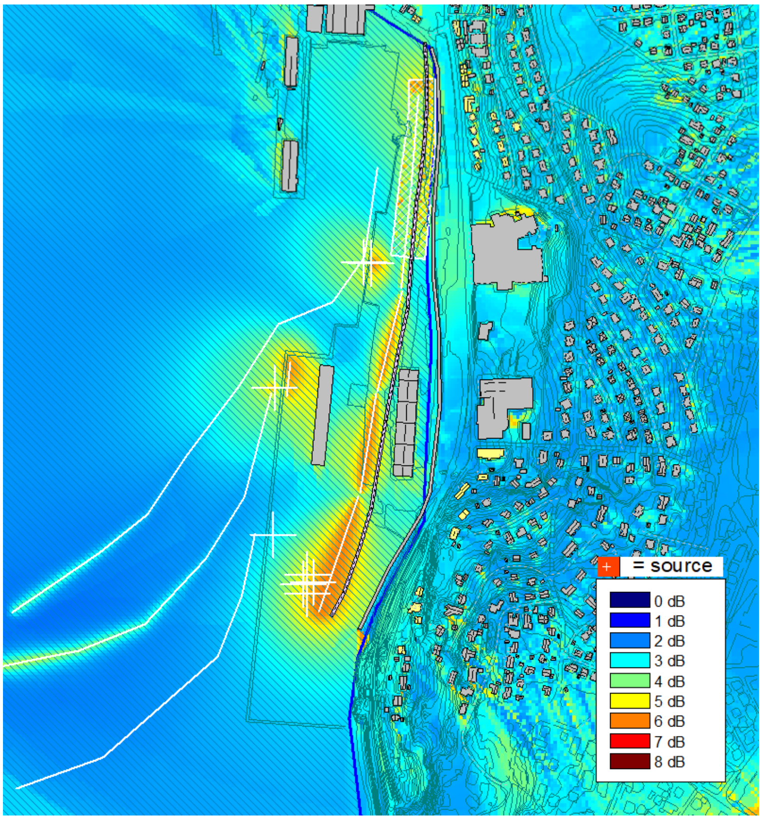

Figure 6: Calculated overall source standard deviation σ in dB for a harbour with receivers (houses) in close proximity (< 200 m). Number of active sources: 18

5 Overall uncertainty including propagation standard deviation

For an industrial/harbour noise project which the author considers to be "normal", distances between source and receiver are typically larger than distances between sources. Therefore, possible propagation errors between source and receiver are easily made for all involved sources the same way (as they propagate in roughly the same direction), meaning that propagation uncertainty for the receivers cannot be considered to be statistically independent. Standard deviation as stated in the calculation method must hence be considered for the overall result and should not be reduced considerably when the number of sources increases.

As a test case, propagation standard deviation for the facility shown in Figure 3 has been approximated with equation (3) as a function of distance, using the conservative assumption that all propagation paths receive the same amount of uncertainty, i.e. that propagation uncertainty for the sources is highly correlated. This has been done by calculating propagation standard deviation from an assumed "centre" of the facility, as shown in Figure 7. Note that finding a centre would require more thought in a project with large distances between the sources. The same figure also shows the overall standard deviation (source uncertainty and propagation uncertainty, combined by eq. (4)), and multiplied by 1,645 as a basis for calculating the upper 95% confidence interval for overall uncertainty (5).

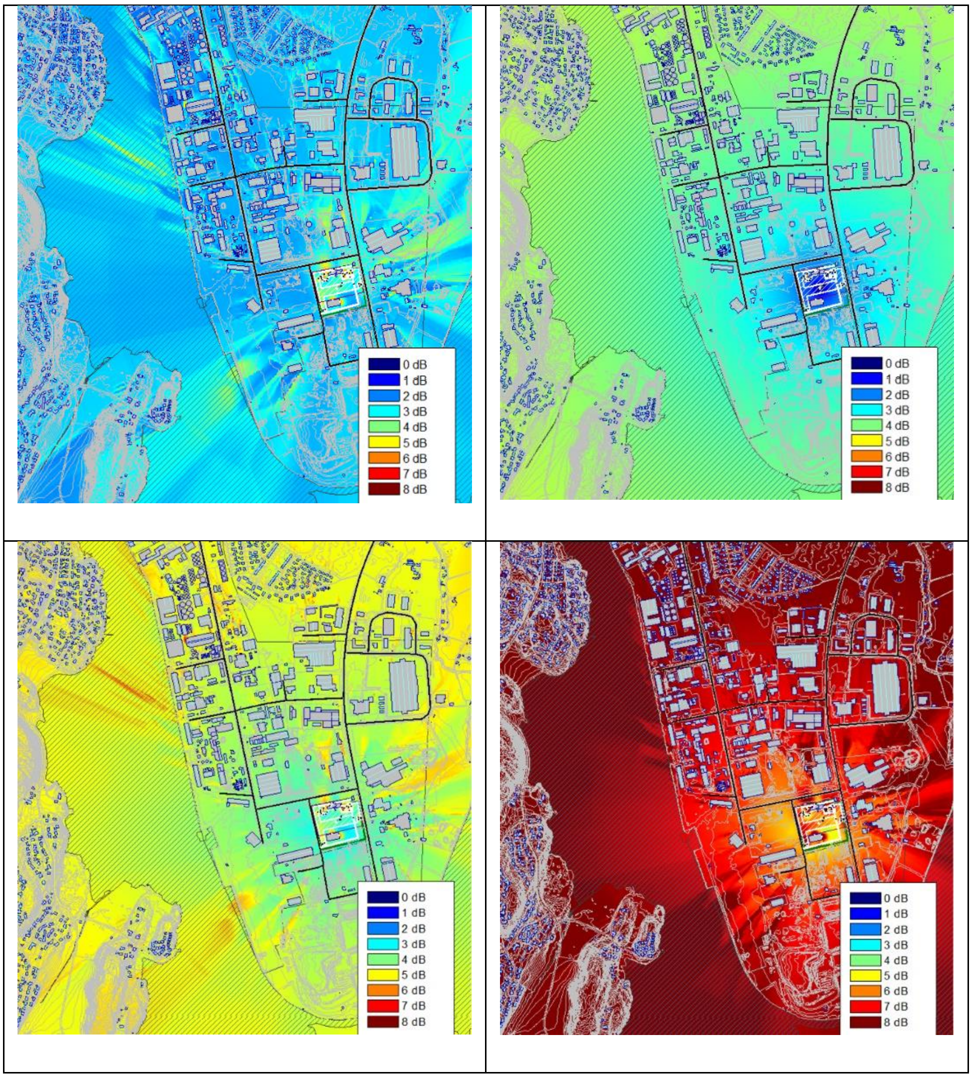

Figure 7: Standard deviation σ from only source uncertainty (upper-left), propagation uncertainty (upper-right), both combined (lower-left), and multiplied by 1,645 as a basis for assessing the upper 95% confidence level in dB (lower-right).

6 Conclusion

A main concern in industrial noise projects is the uncertainty of the results, due to both source and propagation standard uncertainty. For a consultant, especially the likeliness that calculated satisfactory results really are satisfactory is crucial, and strategies to assess uncertainty in such a project are beneficial.

By estimating standard deviations for single sources, overall source standard deviation can easily be calculated and visualized on the same map type as the calculated noise levels. The goal of this quantification of uncertainty isn't necessarily the calculated value itself, but the identification of "weak spots" in the calculation model. Basically, high values at receiver positions correspond to dominance of one or few uncertain sources. This enables the consultant to focus on sources which contribute to a high uncertainty at the receiver. For these identified sources, special care should be taken about assumptions made about the L_w, the directivity, the active time etc. in order to reduce source uncertainty effectively. A practical, additional approach for consultants in these cases is to measure immission values at well-defined positions for situations where dominance of one source is expected, and check/calibrate possible source level errors with them.

For receivers which are affected by a larger number of noise sources with immission levels at the receiver and source uncertainties in the same order of magnitude, overall source uncertainty will most likely not be the main cause of uncertainty. This is especially true for receivers in larger distance from the sources, where propagation uncertainty will be large. Whether this is the case or not can be visualized with uncertainty maps.

Calculating and visualizing propagation uncertainty, overall uncertainty (by source and propagation) and confidence intervals can also be done. However, the consultant has more direct influence on the correctness of the sources than on the propagation, so we find the visualization of source standard propagation more useful in the daily work.

Further analysis regarding statistical independence of sources and propagation should be carried out, in order to derive a more realistic approach which takes into account correlated sources.

References

[1] Kragh, J. et al: Environmental Noise from Industrial Plants: General Prediction Method, issue 32. Danish Acoustical Laboratory, 1982.

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[4] M-290 – Måling av støy fra industri. Sintef, 2015

[5] Probst, W. Uncertainties in the prediction of environmental noise and in noise mapping. Acoustique techniques n. 40, 2015.