Buenos Aires – 5 to 9 September, 2016
Acoustics for the 21st Century…

PROCEEDINGS of the 22nd International Congress on Acoustics

Smart City Sound Monitoring: Paper ICA2016-330

Removing local sound disturbances from industrial noise monitoring at long distance

Peter Wessels(a), Frits van der Eerden(a), Tom Basten(a), Bert de Coensel(b,c), Dick Botteldooren(c), Timothy van Renterghem(c), Luc Dekoninck(c), Vincent Spruytte(b), Alphonso Makovec(d)

(a) TNO, Netherlands, peter.wessels@tno.nl, frits.vandereerden@tno.nl, tom.basten@tno.nl
(b) ASAsense, Belgium, bert.decoensel@asasense.com, vincent.spruytte@asasense.com
(c) Ghent University, Belgium, bert.decoensel@intec.ugent.be, dick.botteldooren@intec.ugent.be, timothy.van.renterghem@intec.ugent.be, luc.dekoninck@intec.ugent.be
(d) A.F.M. state of the Art 4 Millions, Netherlands, info@afmnl.nl

Abstract

Industrial areas with heavy industry may cause annoyance for neighboring residential areas. Especially sources that emit low frequency noise can cause annoyance in residential areas several kilometers from the industry. At these distances the low frequency sound propagation is largely dependent on the meteorological conditions. Height dependent wind and temperature profiles result in a varying effective sound speed over altitude, causing upward or downward sound paths. Depending on the meteorological conditions this can have a significant effect on the acoustic transfer from source to receiver. This paper presents a method to estimate the acoustic immission caused by heavy industry. Acoustic data is collected by monitoring of an actual industrial area, over long distance and over a time period of multiple months. A meteorological acoustic transfer model combined with measurement based source emission estimations is used to estimate the immission of the industrial sources in a residential area. Transfer distances range from 2 up to 10 km. Together with the emission of the industrial sources also the acoustic immission is continuously measured by acoustic monitoring stations within the residential area. The calculated immission estimates are used to differentiate between the industrial related noise and all other sounds within the residential area. When considering possible annoyance due to the industry, the monitoring of other sounds is not relevant and should be excluded from the analysis. This differentiation is made by comparing the estimated immission with the measured sound level for the residential area. The method is an alternative for the audio classification methods of industrial or other sounds.

Keywords: monitoring, excluding, disturbances, industrial sound

Removing local sound disturbances from industrial noise monitoring at long distance

1 Introduction

Acoustic monitoring is a tool to gain more insight into complex acoustical situations. In contrast to short term measurements, monitoring can provide better insight in sound level changes over time. It can be used to obtain more reliable average sound levels and provides an insight into the effect of changes, measures and meteorological conditions. A weakness of long term monitoring is that usually no human operator is present to safeguard the quality of the measurements. An operator can, for example, choose to exclude moments in which acoustic disturbances pollute the measurement. A solution is a monitoring system that discriminates between the targeted sounds and disturbances.

This paper discusses a long term monitoring project called ‘Geluidmeetnet Maasvlakte’ with a focus on the method of excluding acoustic disturbances from the monitoring data. In the project the sound production of a large industrial area (IA) and the sound immission in a nearby residential area (RA) are monitored during a period of a full year. The project was initiated by the DCMR (the environmental protection agency in the Rijnmond region in the Netherlands), the municipality of Westvoorne (which includes the RA: the town of Oostvoorne) and The Port of Rotterdam. The applied monitoring system has been developed by 4 parties: Ghent University, TNO, ASAsense, and A.F.M. state of the Art 4 Millions.

The aim of the project is to identify which of the sources in the IA contribute most to the noise annoyance in the RA. Monitoring has started January 2016 and will last until the end of December 2016. In addition to monitoring, and outside the scope of this research, a panel of RA inhabitants also provides feedback concerning the noise, so monitoring results and the feedback can be combined.

The IA is roughly 5 by 6 km in size and houses multiple industrial companies (see Figure 1). A monitoring network of 4 large arrays (each consisting of 40 microphones) [1] and 10 acoustic monitoring stations, is used to map the sound production in the entire IA [2]. The sources in the IA are, typically, continuously active for multiple hours (day and night). The source mapping is done every 10 minutes. The acoustical transfers used in this process are approximated by a meteorological acoustic transfer model [3]. A meteorological model (HiRLAM) and 4 meteorological monitoring stations in the area provide its input.

Data generated by all microphone arrays (about 1 TByte/month) is transferred to a number of internet gateways (optical fiber networks) over licensed 3.5 GHz radio links using OFDM technology, with fall-back to 4G LTE or 3G for load balancing, and are then sent to a set of central storage and computing servers for further processing.

The sound levels in the RA, which lies at about 2 km distance from the IA, are (also) measured by 4 acoustic monitoring stations [4]. These levels are compared with the sound levels that are expected at the RA, based on the obtained source level maps and the acoustic meteorological transfer model. This comparison is the basis for the disturbance exclusion method discussed in this paper.

Figure 1: Maps showing (left) the Industrial Area (IA) and Residential Area (RA) and (right) the locations of multiple arrays and both acoustic and meteorological monitoring stations.

It is remarked that the acoustic contributions from the industry, road and rail are currently within the legal noise limits. This paper will not show absolute sound levels, since the research is not completed yet. The results in this paper are based on one month of monitoring data and should therefore be considered as preliminary. The results of a full year of data might reveal different insights.

2 Methods for removing local sound disturbance from monitoring data

The remainder of this paper focuses on the removal of acoustic disturbances from the monitoring data in the RA. This is important since it is not likely that all sounds in the RA are caused by the IA. Height dependent wind and temperature profiles result in a varying sound speed over altitude, causing upward or downward refracted sound paths. Depending on these meteorological conditions only a part or even none of the, mostly low frequent, sound in the RA can be attributed to the activities within the IA.

A first option is to perform audio classification on the monitoring data and identify either the targeted sounds or the disturbances. In order to build such a classifier, a training set and a set of features are needed. The needed training set is a collection of labelled audio examples for the classification algorithm to learn, the features are properties of the audio that the algorithm uses to separate the audio into classes. Such an approach is feasible in case the acoustic problem is well-defined and limited in scope [4]. The approach is unsuited for application in the

‘Geluidmeetnet Maasvlakte’ case, were the possible sources are assumed to be rather large in number and not all known beforehand.

Another option is to only remove certain short and loud outliers from the data. For example: a vehicle passing near a RA monitoring post, will only momentarily effect the RA measurements. Exclusion of sudden loud measurements can for instance be done by calculating the L90; the sound level that is exceeded during 90% of the measurement time. This method however does not determine whether the (remaining) sound is caused by the IA. The sources on the IA are typically active for hours and are characterized in the RA as a low frequent humming. The L90 measure does not differentiate between a background noise due to sounds of the RA, or one dominated by sounds from the IA.

The third and final approach that is discussed in this paper is a model vs. measurement based exclusion. In this method the sound power levels of the relevant IA sources are estimated and a model based prediction of the resulting immision at the RA receivers is made. Exclusion of disturbances in the measurement data is done by removing all measurements that do not sufficiently match the modelled sound levels. The method requires accurate estimates of the source sound levels and an accurate estimate of the sound transfer. It also helps to have a rather large attenuation between source and receiver. High sound levels at the RA must then be caused by very loud sources in the IA, which are easier to (dis)prove by measurement at the IA.

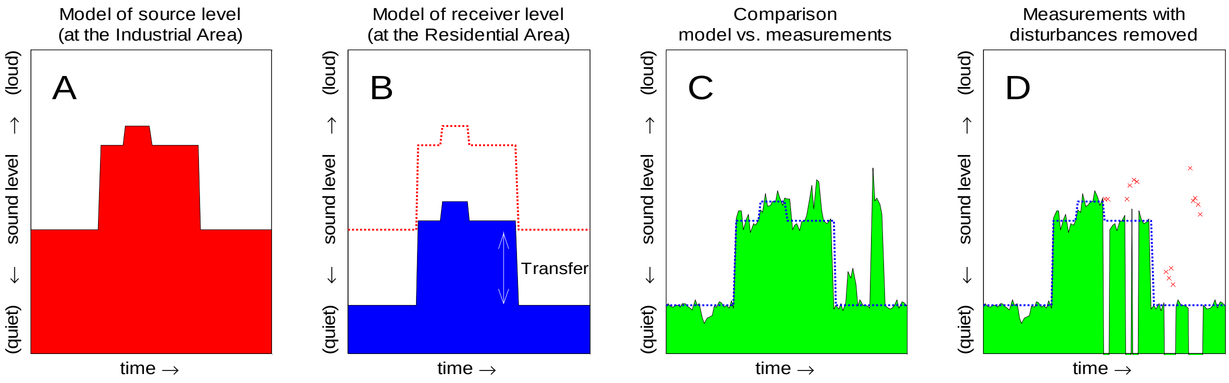

Figure 2: from left to right: fictional source level over time; expected immission over time; fictional measurements over time (with disturbances); measurements after exclusion (with crosses marking the excluded samples).

Figure 2 illustrates the process for a single source and a single receiver. The given sound level over time can represent a broadband level, or a specific one-third octave band. Figure 2 A shows the development of a fictional source sound level over time. Figure 2 B shows the expected sound levels at a receiver at some distance from the source. The only difference is the (meteorological dependent) attenuation. Figure 2 C shows (fictional) measurement values at the receiver location. These resemble the expected sound levels, but also contain some (local) disturbances. Figure 2 D finally shows the result after the exclusion of all sound levels that do not match with the prediction, using a certain threshold for exclusion.

3 Results

In the current project the acoustic sources are not measured directly, but the source locations and the corresponding source levels are estimated by the monitoring network in the IA [2]. The monitoring network in the RA does not contribute to this estimate. In this paper we start with the assumption that the found source levels are sufficiently correct. The same holds for the acoustic transfers from IA to RA. The distances range from 2 to 10 kilometers and the transfers are assumed to be modelled sufficiently accurate, using the meteorological model with meteorological data as input [3].

3.1 Functioning of the exclusion method

The exclusion method is applied at data intervals of one second and for each one-third octave band separately. An exclusion threshold of +10 dB is applied. In other words: only where the measurement data in the RA contains one-third octave band sound levels 10 dB higher than the best estimates predict, these measurement are excluded. It is thus assumed that the combination of source mapping and transfer model is accurate within 10 dB. Measurement values lower than the expected values are never excluded.

Figure 3 shows how the model vs. measurement exclusion alters the spectrogram. The top part of Figure 3 shows the original spectrogram (the actual sound levels have been replaced by a relative scale because of confidentiality). The red events in the spectrogram are in fact cars passing on the road next to the monitoring station. The lower part of Figure 3 shows the spectrogram after exclusion. The remaining measurement data all fits within the 10 dB threshold of the model.

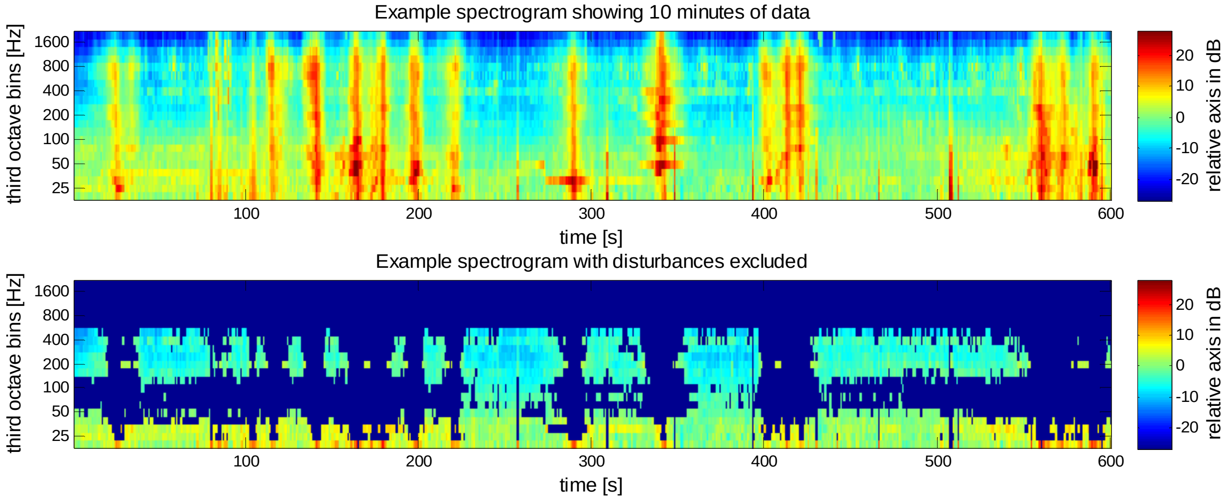

Figure 3: Spectrogram with 10 minutes of RA data, before exclusion of disturbances (top) and after (bottom).

It is interesting to explore how well model and measurements compare (before exclusion of data). In an ideal case, without any disturbances the model would exactly predict the measurement results. A comparison of (many) measurement values against (many) model values, as sketched in Figure 4, would then result in a diagonal line. The measurements do however contain (local) sounds that are not included in the model. These disturbances will cause higher sound levels than modelled. Also in case of a quiet IA, or when the attenuation is high (wind from RA to IA) the model predicts unrealistic low RA levels that drop below the background noise of the RA itself.

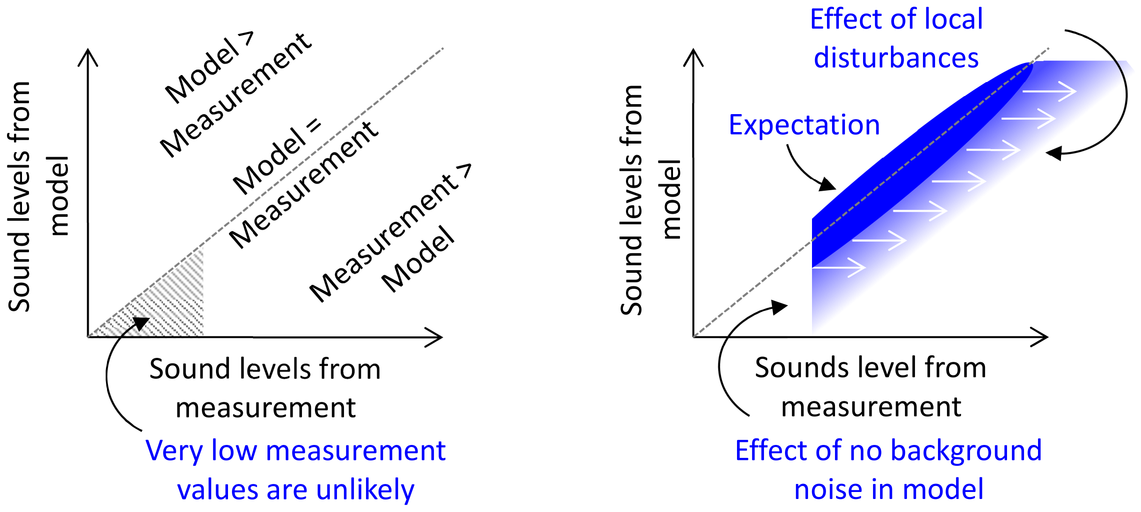

Figure 4: Sketch of model vs measurement (before exclusion) comparison expectations.

Therefore the following results are expected from the comparison:

1. A good match between model and measurement results in a majority of data points close to the diagonal;
2. For low modelled levels the measured levels are expected to be higher than the model results, due to (normal, non-industrial) background noise;
3. More measurement values are expected at the right hand side of the diagonal, since the measurements are likely to contain disturbances which are not included in the model;
4. Not many data points are expected at the left hand side of the diagonal, since it is unlikely that the model overestimates the sound levels in the RA.

Figure 5 shows the comparison for all four RA monitoring stations. The actual sound levels have been replaced by a relative scale because of confidentiality. The color values indicate how often a combination of measured and modelled values occur. Red is most often, dark blue is least often. The period used for the analysis compared all measurement results versus model results from May 1, 2016 to May 31, 2016. Broadband unweighted sound levels are used.

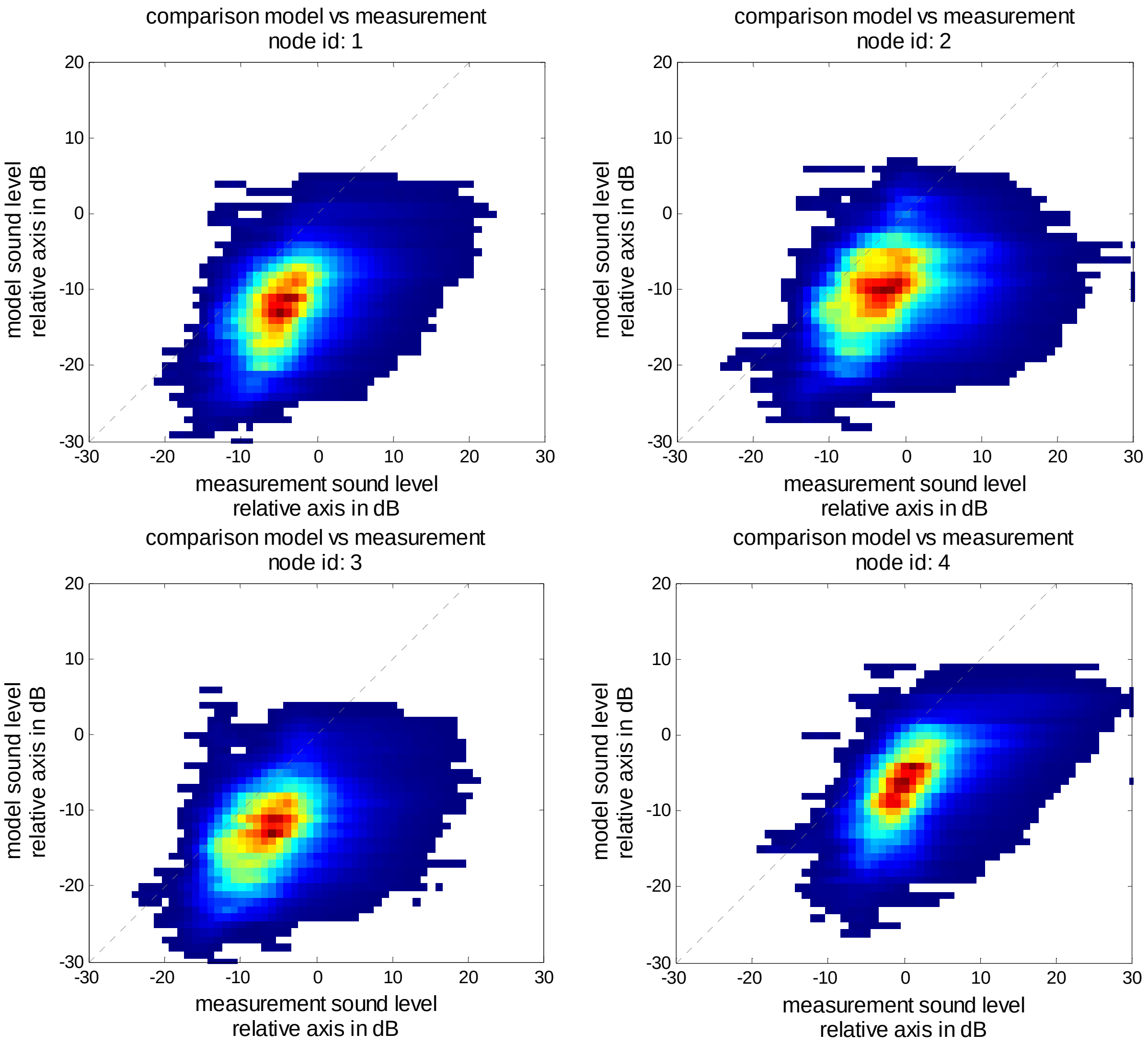

Figure 5: Comparison of broadband sound levels from model and from measurements (before exclusion), for all four RA monitoring locations.

The results in Figure 5 show that, on average, the measurements (before exclusion) contain about 5 dB louder sound levels than the model predicts. The majority of samples lie between 0 and 10 dB to the right of the diagonal. This offset can be caused by both a model error and by all the contributions from disturbances from local sounds in the RA (not included in the model). The distributions in Figure 5 also show a larger spread on their right side. It could either be caused by a (not expected) model bias, or again by the local disturbances in the RA.

In case we apply our exclusion method to the one-third octave band measurements (as in Figure 3), and then calculate the broadband unweighted ‘measured’ values again, a result is obtained which is given in Figure 6. The result is shown to illustrate the effect of the method, not to prove its correctness.

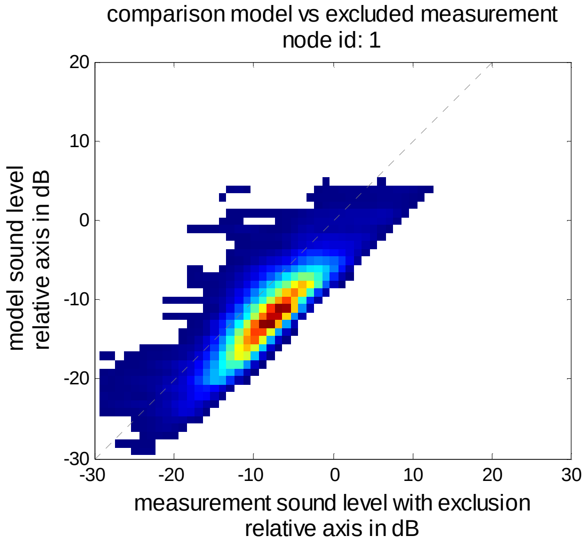

Figure 6: Comparison of broadband sound levels from model and from measurements after exclusion of disturbances.

3.2 Additional data comparisons

The previous section showed how the model based exclusion method functions. The main assumptions are that the source mapping and the acoustic transfers are always sufficiently accurate. With the current setup and results it is not possible to prove that this is indeed always the case. Two additional comparisons were done in order to further analyze the quality of the method.

The first analysis compares the average measured sound levels, the measured sound levels after exclusion, the modelled sound level and the L90 (per 10 minute period). Figure 7 shows these levels during a 24 hour period as averages over all four RA monitoring stations, with data averaged over a period of one month.

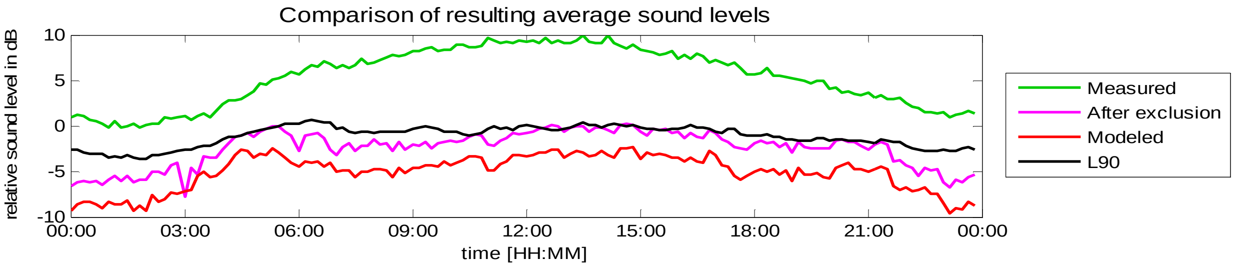

Figure 7: Comparison of average measured sound levels, measured sound levels after exclusion, modelled sound levels and the L90. Data is averaged over all four monitoring posts, for every 10 minutes per 24 hour, using one month of data.

In Figure 7 the measured sound levels are about 10 dB higher than the modelled sound levels. The measured sound levels also show the largest dynamic range with a maximum peak around noon. The L90 sound levels however, in which the effect of short disturbances is suppressed, are less loud and do not show a maximum at noon. Also, the modelled values do not support the idea that the higher measured values are due to higher sources levels or due to a better sound transfer condition. So the conclusion may be drawn that the higher measurement values can be attributed to short (local) disturbances. The L90 curve is probably a better representation of the industry related sound than the raw measurement results.

The measured values after exclusion match well with the L90 values. The 10 dB threshold, applied to each time step and one-third octave band, results in excluded measurement values that are about 2.6 dB louder compared to the model. As mentioned before, the model is capable of predicting values below a normal background level. The sound levels before 0:50 and after 22:00 show that for these periods the L90 most likely represents the normal background level, and not the contribution of the IA.

In a second comparison, the exclusion of measurement data was compared between the four monitoring stations in the RA. An analysis was made of the number of monitoring stations that exclude identical samples (identical timestamps and identical one-third octave bands). Figure 8 shows the result on a 24 hour time axis, with data averaged over a period of one month and with a time resolution of 10 minutes.

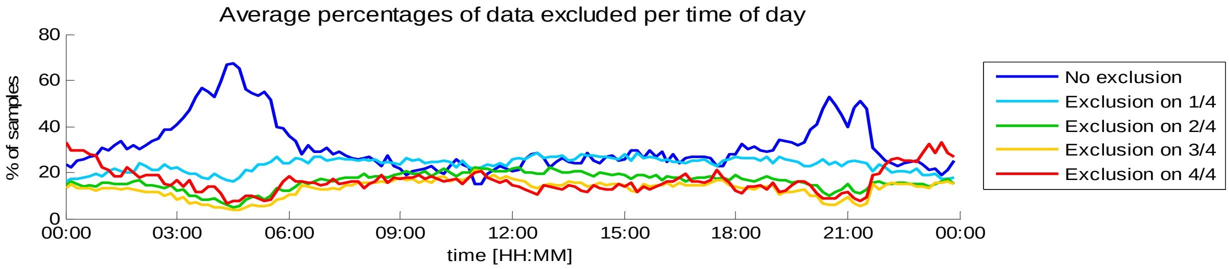

Figure 8: Comparison of the average number of samples that: is not excluded by any monitoring station (blue); excluded by only one monitor station (cyan); excluded by two monitor station (green); excluded by three monitor stations (orange); excluded by all four monitor stations (red). Data is shown as averages for every 10 minutes per 24 hour, using one month of data.

The five lines in Figure 8 show the average number of samples that are not excluded and how many are excluded by one, two, three or four monitoring stations, respectively.

Apparently there are significant differences with respect to the time of day. As discussed before, the measured sound levels before 0:50 and after 22:00 are most likely due to (normal) background noise. It is therefore not surprising that during this period the number of samples excluded by all four monitoring stations is highest. The two peaks at 4:15 and 20:50 indicate periods in time where the four monitor posts exclude the least samples simultaneously. The explanation for this could be the lack of local sound disturbances during these time periods, combined with a sound contribution from the IA loud enough to rise above the (normal) background level.

4 Conclusion

The quality of acoustic monitoring data should be improved by removing non relevant disturbances from the measurements. In this paper the targeted industrial sources have slow varying emission levels. Only short disturbances in the immision measurements at the residential area could be removed by calculating the L90. The immissions of the targeted sources was strongly dependent on the meteorological conditions. Depending on the meteorological conditions only a part or even none of the sound in the residential area was due to the activities within the industrial area. A meteorological acoustic transfer model with source level measurements as input was used successfully to determine which measurements could be attributed to the industrial area. A classification method is not necessary when the proposed method is applied.

Acknowledgments

The development of the Maasvlakte sound measurement network ("Geluidmeetnet Maasvlakte") was commissioned by DCMR in the framework of the BRG (Bestaand Rotterdams Gebied), and received financial support from the City of Rotterdam, the Province of South Holland, the Port of Rotterdam and the Government of the Netherlands. Furthermore, the authors would like to acknowledge the contributions of Coen Boogerd (DCMR), Rogier Wigbels (DCMR), Frank Wolkenfelt (Port of Rotterdam), Gert van Antwerpen and Frans Staats (TNO).

References

[1] Bert de Coensel, Dick Botteldooren, Timothy van Renterghem, Luc Dekoninck, Vincent Spruytte, Alphonso Makovec, Peter Wessels, Frits van der Eerden, Tom Basten, Robust microphone array beamforming for long-term monitoring of industrial areas, *proceedings of ICA*, Buenos Aires, Argentinia, 5-9 September, (2016)

[2] Dick Botteldooren, Timothy van Renterghem, Bert de Coensel, Luc Dekoninck, Vincent Spruytte, Alphonso Makovec, Frits van der Eerden, Peter Wessels, Tom Basten. Fusion of multiple microphone array data for localizing sound sources in an industrial area. *proceedings of Internoise*, Hamburg, Germany, 21-24 August, (2016)

[3] Frits van der Eerden, Peter Wessels, Arjo Segers, Tom Basten, Bert de Coensel, Dick Botteldooren, Timothy van Renterghem, Luc Dekoninck, Vincent Spruytte, Alphonso Makovec, Time varying sound propagation for a large industrial area, *proceedings of Internoise*, Hamburg, Germany, 21-24 August, (2016)

[4] P. Wessels, T. van Zon, T. Basten, Automatic classification of urban traffic noise onboard an acoustic monitoring system, *proceedings of Internoise*, Innsbruck, Austria, 15–18 September, (2013).