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# Long-term monitoring of time-varying sound propagation from a large industrial area

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## ABSTRACT

A long-term monitoring project, with 12 months of continuous operation time, is described where the sound sources within a large industrial area as well as the sound levels in the nearby residential area are measured. The sources in the industrial area may give rise to complaints from the neighboring residential areas, at several kilometers distance. Especially sources that emit low frequency noise can contribute, depending on the meteorological conditions. This paper focusses on the model based long-term monitoring and the effects of the time varying sound propagation that is needed to determine the source strengths within the industrial area and the relevance of the sources for the nearby community. For this purpose data from a meteorological model is combined with measurements from multiple meteorological masts. The time-varying sound propagation for all possible sources is obtained near real-time. Besides the emission of the industrial sources, also the acoustic immission in the residential area is continuously measured by acoustic monitoring stations within the residential area. The calculated estimates of the immission are used to differentiate between the industrial related sounds and other sounds within the residential area. When considering possible noise nuisance due to the industry, the monitoring of other sounds should be excluded from the analysis. This differentiation is made by comparing the estimated immission with the measured sound levels in the residential area. It will be shown that this monitoring project captures the time-varying industrial noise as perceived in the residential area, whereas a standard noise model uses a constant sound propagation based on an average meteorology.

Keywords: Monitoring, Propagation, Meteorology
I-INCE Classification of Subjects Number(s): 24.6, 52.5, 76.1

## 1. INTRODUCTION

A large industrial area is considered, located near the sea and with a residential area at several kilometers distance. Noise complaints occur whereas the contributions from the industry, road and rail are within the legal noise limits. For these distances between the sources and the residential area it may not be clear what sources contribute to the complaints. Especially because the meteorology can be complex in this area, due to several water-land crossings, and because several source types are present in the area.

Acoustic monitoring is a tool to gain more insight in complex acoustical situations. Short-term measurements are commonly carried out, but to capture sound level changes over time long-term monitoring is preferred. This paper focusses on model based long-term monitoring, by combining the

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sound propagation model results with measurements. The effects of the time varying sound propagation are needed to determine the source strengths within the industrial area and the relevance of the sources for the nearby community. Note that a standard noise model uses a constant sound propagation based on an average meteorology.

Section 2 describes the model based monitoring system (Geluidmeetnet Maasvlakte), as developed by the University of Ghent, TNO, ASAsense, and Art For Millions. This project was initiated by the DCMR (the environmental protection agency in the Rijnmond region), the municipality of Westvoorne and The Port of Rotterdam. Besides acoustic monitoring for one full year in 2016, a panel of inhabitants of Oostvoorne was providing feedback on noise coming from the monitored area in a separate project.

Section 3 considers the effects of the time-varying sound propagation. The sound propagation results are used to calculate the relevance of the source areas for the residential area, but are also applied to estimate the source strengths by using nearby monitoring stations.

Section 4 describes the long-term monitoring results in the residential area. Here, the local disturbances have been excluded in the measurements by using the model based contributions of the monitoring system.

Section 5 ends with conclusions. It is remarked that the data analysis is ongoing so that no final conclusions can be provided at this stage.

## 2. OVERVIEW OF MODEL BASED MONITORING SYSTEM

To localize the sound sources 4 arrays have been installed at the edges of the industrial area. The arrays are 50 meters wide and consist of 40 microphones each to determine the direction of arrival of the sound at their location. By combining the data from the 4 arrays the sound can be localized (4).

Figure 1 shows an overview of the Industrial and Residential Areas, denoted as IA and RA, respectively (Maasvlakte and Oostvoorne). At the right-hand side, the red markers show the microphone arrays. The arrays are referred to as North, West, South, and East. The positions of 10 IA and 4 RA microphone positions are shown with blue markers.


Figure 1 – Left: indication of the size of the industrial area (IA) and the distance to the residential area (RA). Right: Locations of the microphones, arrays, and meteorological masts.

As the meteorology can be complex in the area, 4 meteorological masts were placed distributed over the area. These are indicated with the yellow markers in Figure 1. The masts provide data each minute on temperature, humidity, pressure, rain, windspeed and direction. The wind direction and speed are measured at a height of 10 meters..

To determine the time varying sound propagation between each source area and each receiver position the wind, temperature and humidity needs to be known, preferably at several heights. Meteorological data from HiRLAM (High Resolution Limited Area Model) is used which provides data at several heights (10 levels with a maximum of 700 meters are used). Data assimilation is then applied to combine the HiRLAM data with the measurements to obtain data for periods of 10 minutes.

For each path between a source area and a receiver (microphone/array in either the IA or RA) a representative sound speed profile is determined for each period of 10 minutes, based on the meteorological data. This profile is fitted to one of 27 profiles for which the sound propagation has been calculated beforehand. The sound propagation results were obtained with a numerical model (PE) that considers, amongst others, the refraction of sound (2).

Figure 2 shows an example of a 10 minute period for the meteorological data (left) and the sound propagation effect towards array North (right). Each source area, 200x200m$^2$ (800+ source areas) is indicated with a red circle. The wind speed and wind direction is shown at 30m height, indicating a South-West wind direction. The sound transfer towards the array excludes the effect of distance for clarity. It shows, amongst others, the more favorable propagation over a water surface.

A more detailed description of the model based monitoring system is given in (1).

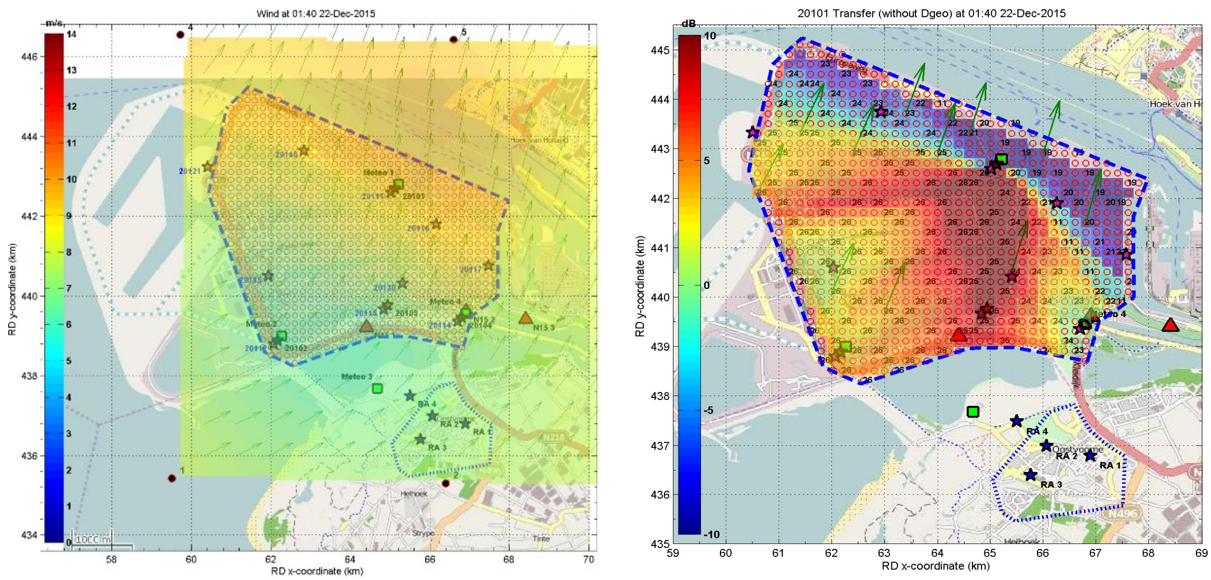


Figure 2 – Left: Wind speed and wind direction displayed at 30m height via a combination of 4 meteorological masts (green squares) and meteorological data (6 black circles, 4 shown). Right: Sound propagation for each source area (IA) towards Array North, without the effect of distance.

## 3. TIME-VARYING SOUND PROPAGATION

This section highlights, respectively: I) the time-varying meteorology, II) the time-varying sound propagation over an industrial area, III) the meteorological dependent screening of an earth berm, and IV) the sound transfer results towards the residential area over 12 months.

### 3.1 Time-varying meteorology

To illustrate the time-varying meteorology Figure 3 shows the wind speed and wind direction during 5 days in September. Data from two meteorological masts at 10m height is displayed (West and South locations, see Figure 1), using one minute averages. Clearly, the meteo at both locations is not identical. Also shown is the meteo data as used by the monitoring system at the Array South location. There is no meteorological mast at that location, so the combination of model and meteorological mast data in the area is used to obtain the 10 minute averages as used by the monitoring system. As a comparison, the archived meteorological data from a KNMI meteorological mast (Dutch meteorological institute) is shown on an hourly basis. This mast is located in Hoek van Holland several kilometers from the industrial area. In general, the wind directions agree, but the registered wind speed is higher in Hoek van Holland.

The bottom figure shows the sound attenuation (or propagation) towards the residential area and towards the opposite direction of Array North. The wind direction is a major driver for the time-varying sound propagation. Nevertheless, it will be shown in section 3.4 that by using only the wind direction (at a single height) it is not sufficient to predict the time-varying sound propagation.

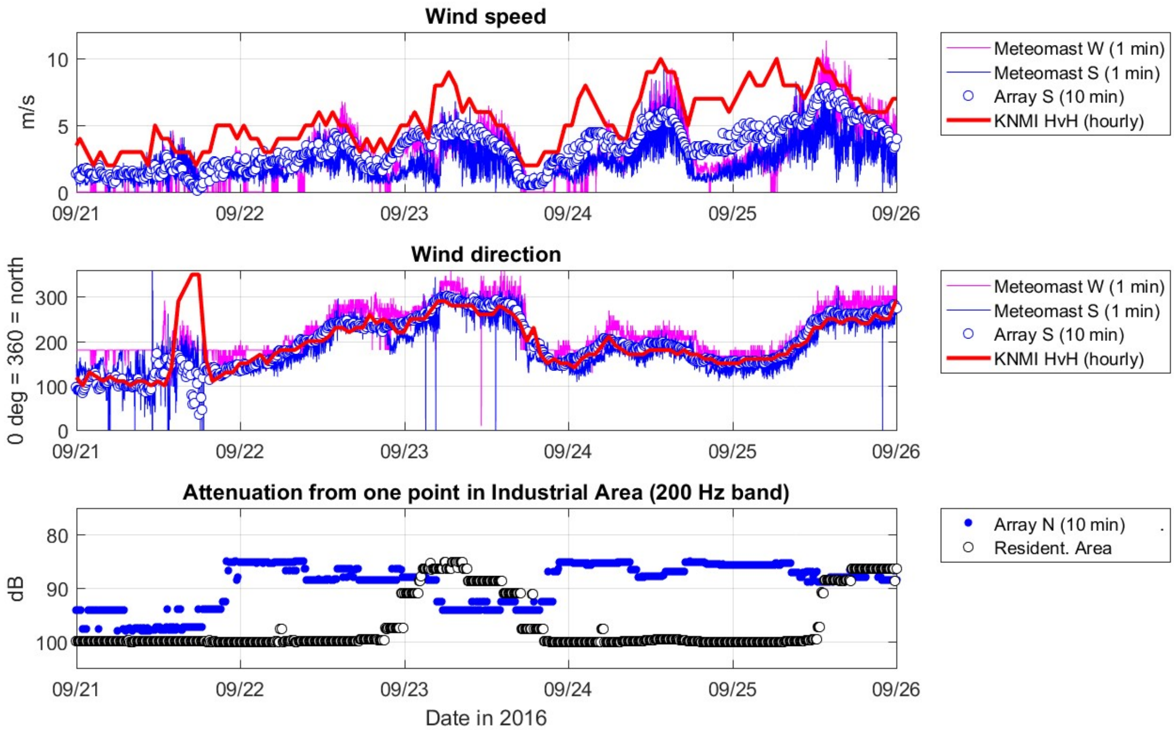


Figure 3 – Example of measurements from the meteorological masts (each minute), the applied meteo for an array (each 10 minutes), and a comparison with nearby meteo data from KNMI (hourly, in Hoek van Holland). Bottom figure: example of the sound attenuation towards Array N and the Residential Area in the 200 Hz one-third octave band, using a minimum attenuation effect due to meteorology.

### 3.2 Attenuation over industrial areas

The attenuation of sound during propagation over an area with industrial installations is taken into account. It is based on the ISO 9613-2:1996 attenuation ($A_{site}$), but extended with a meteorological dependency. The attenuation for the complete area, industrial and recreational, is a weighted average of propagation over acoustically hard, soft and very soft ground. The ground types (e.g. industry/buildings, water, bare ground) are indicated in the right-hand side of Figure 4.

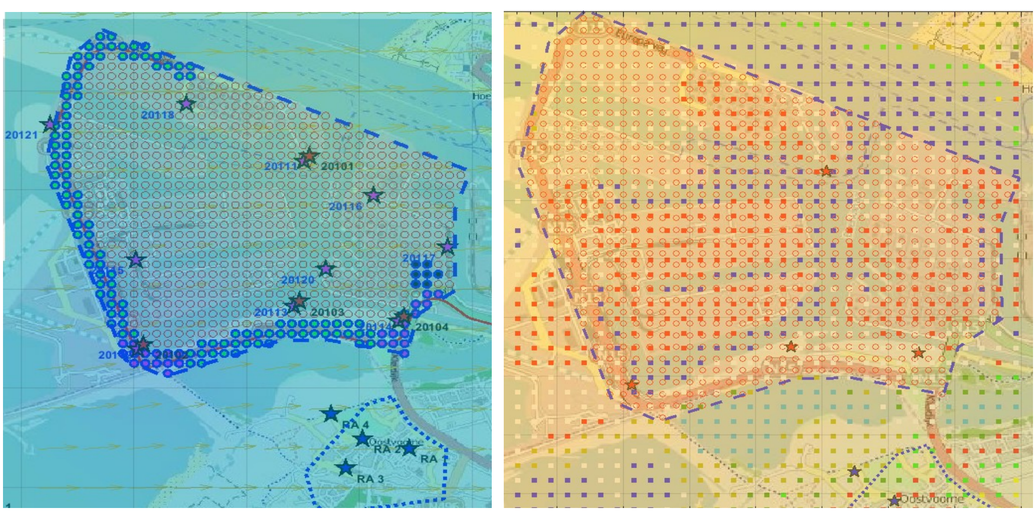


Figure 4 – Left: Each 200x200 m$^2$ source area indicated with circles; red for industry, blue ones for different source types or source heights. Right: different ground types indicated with colored squares; e.g. red = industrial area, white = bare ground.

The left-hand side shows the 200x200 m$^2$ source areas indicated with circles. A default source height of 15m is used, considering the averaged building height for this area. The red circles are for industrial sources, the blue ones for different source types or source heights. Note that the range dependent attenuations for 27 profiles and 3 ground types were calculated beforehand.

The attenuation at industrial sites was specifically addressed because additional screening and scattering effects were expected due to various objects like installations, buildings and containers. These effects are also partly accounted for by using a very soft ground. The ISO attenuation for industry uses an attenuation that increases linearly with the propagation distance through the industrial plant (for a curved path), with a maximum of 10 dB. When considering the propagation paths for 27 different sound speed profiles, these distances were determined for each profile. In upwind conditions this distance is linked to the industrial section which contains the source area, with maximum distances ranging from 400 to 800 meters (for decreasing upwind). For downwind conditions the distance over more industrial areas can be used, with a maximum of 10 dB. The ISO values were extended to 31 and 63 Hz bands and lower values were used as scattering is also accounted for by applying a very soft ground.

Figure 5 shows an example of the additional attenuation over an industrial area ($A_{site}$) towards Array N (left) and Array W (right) for a downwind situation. For demonstration purposes a 100 dB source has been applied in each source area, the one-third octave band results were aggregated, and the geometrical attenuation is excluded. It can be seen that for increased distances over industrial areas, the attenuation increases.

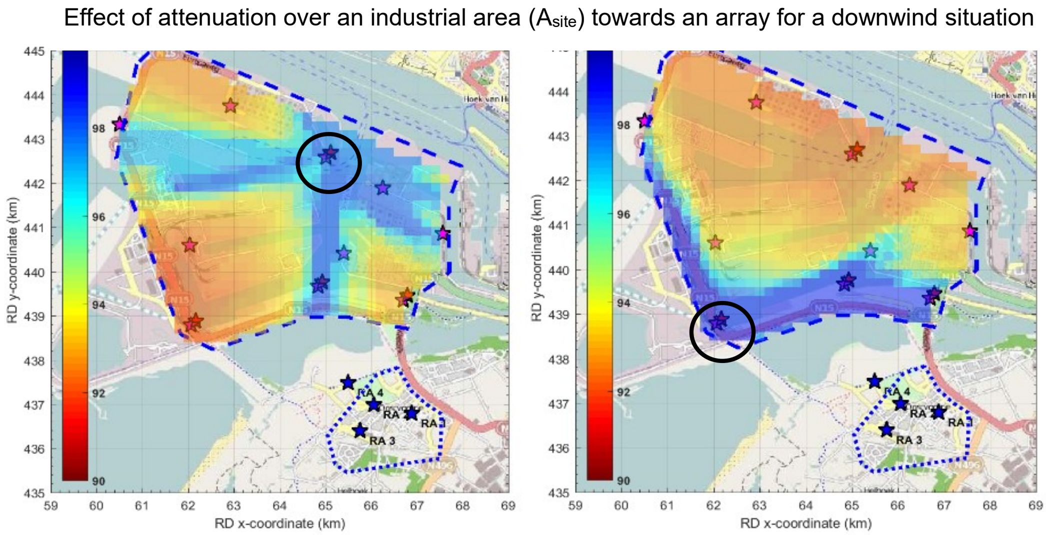


Figure 5 – Effect of attenuation over an industrial area (Asite) towards Array N (left) and Array W (right) for a downwind situation (using a 100 dB source and with one-third octave bands aggregated, without the effect of distance).

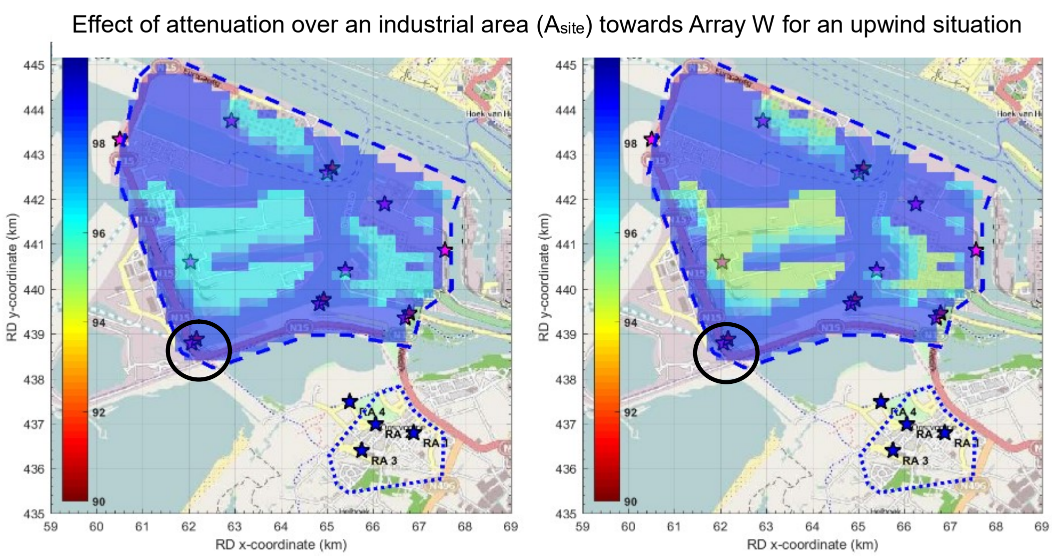


Figure 6 – Effect of attenuation over an industrial area (Asite) for a downwind situation towards Array W for a strong and moderate upwind condition, respectively, without the effect of distance.

Figure 6 shows the attenuation for two upwind conditions. The left-hand side is a strong upwind situation, while the right-hand site is a moderate upwind situation. In the latter case the maximum propagation distance over the industrial site is increased, so that relatively more attenuation results.

### 3.3 Attenuation over an earth berm

The meteorological dependent screening of an earth berm has been taken into account by using the Dutch model for shooting noise (2). A highway is located at the south of the industrial area, which runs up north on the west side, e.g. see Figure 4. The southern part of this highway is screened towards the residential area by a 6 m high berm. The distance to the highway is between 30 and 60 meters. The distance to the residential area is more than 2 km. Figure 7 shows the screening effect of the berm for the upwind, neutral and downwind conditions, for a distance of 45 m from the highway, as a function of frequency. The screening effect increases with frequency, but for increasing downwind conditions the screening effect decreases. A comparison with ISO 9613 is also made, with and without a meteo correction. For this geometry and with a meteo correction a constant screening effect of about 5 dB results.

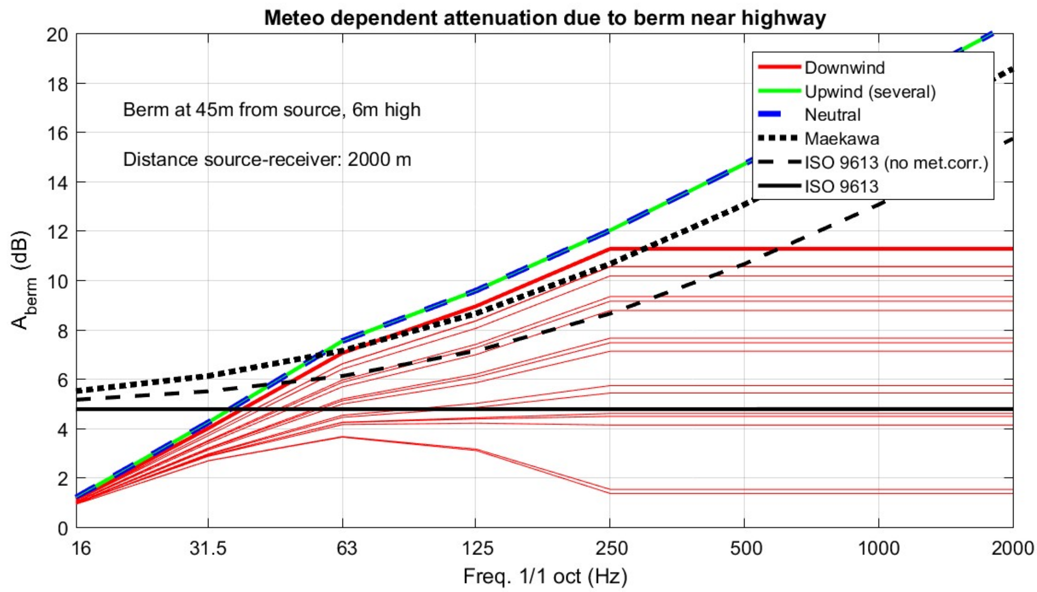


Figure 7 – Attenuation due to a 6m high berm (earth wall) near a highway. Comparison of meteorological dependent attenuation to standard models.

### 3.4 Sound propagation results for 12 months

The model based monitoring system ran for 12 months in 2016. So the time-varying sound propagation, from the center of the industrial area to the residential area, can be obtained as shown in Figure 8. Sound transfer results are given, with the minimum set to 0 dB (and representing a strong upwind condition). A high level indicates a higher received sound level, for the same source strength. For this figure the spectral results were aggregated (using a source without spectral variations; pink noise). Due to the varying meteorological conditions the sound levels vary as much as 15 dB. The variation shows distinct values because of the use of 27 sound speed profiles.

In the figure the different upwind, downwind and (about) neutral wind directions are indicated. The wind direction is taken at 10m height and is an average over the path between the source and receiver. The direction from the center of the IA to the RA is -27 degrees, with respect to the wind coming from the north (=0 degrees). Downwind conditions, shown in red, are defined for wind directions with a maximum offset of ±80 degrees with respect to -27 degrees. Similarly, the upwind conditions are shown in green. The remaining wind directions are considered as neutral and shown in blue. This figure shows that by only knowing the wind direction at 10m height it is not sufficient to predict an increase or decrease of the sound levels in the residential area; i.e. a more detailed knowledge of the meteorological situation is needed.

The legend indicates the percentage of downwind and upwind situations. In The Netherlands a prevailing southwest wind occurs, which explains the higher percentage for the upwind conditions. Also, for the so-called neutral conditions it can be seen that a large number of relatively high sound levels can occur. So it is not obvious that only downwind conditions leads to higher sound levels.

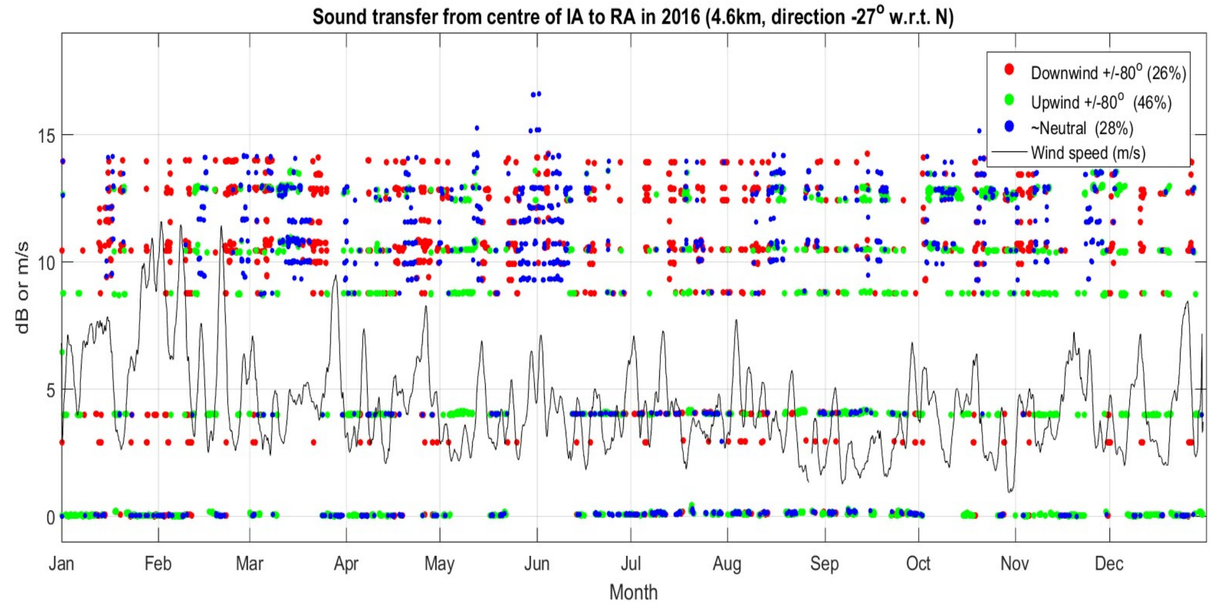


Figure 8 – Relative sound levels from IA to RA for a uniform source and meteorological data as used by the monitoring system (here: hourly based), for downwind / upwind / neutral conditions (using wind direction at 10m height).

## 4. LONG-TERM MONITORING IN THE RESIDENTIAL AREA

The sound levels in the residential area, which is about 2 km south of the industrial area, are measured by 4 monitoring stations. Spectral levels are gathered each second. These levels are compared to the sound levels that are expected from the industrial area, as the contribution from the industry, highway and rail in the residential area is determined with the model based monitoring system. This comparison is the basis for the method to exclude local disturbances in the measurements in the residential area (3).

Figure 9 shows how the model based monitoring results alters the measured spectrogram. The top part shows the original spectrogram for 10 minutes of data (using scaled values as an example). The red events in the spectrogram are due to traffic on the local road next to the station. The lower part shows the spectrogram after exclusion of the local disturbances. The remaining results fit within the 10 dB threshold of the model based monitoring data for the residential area.

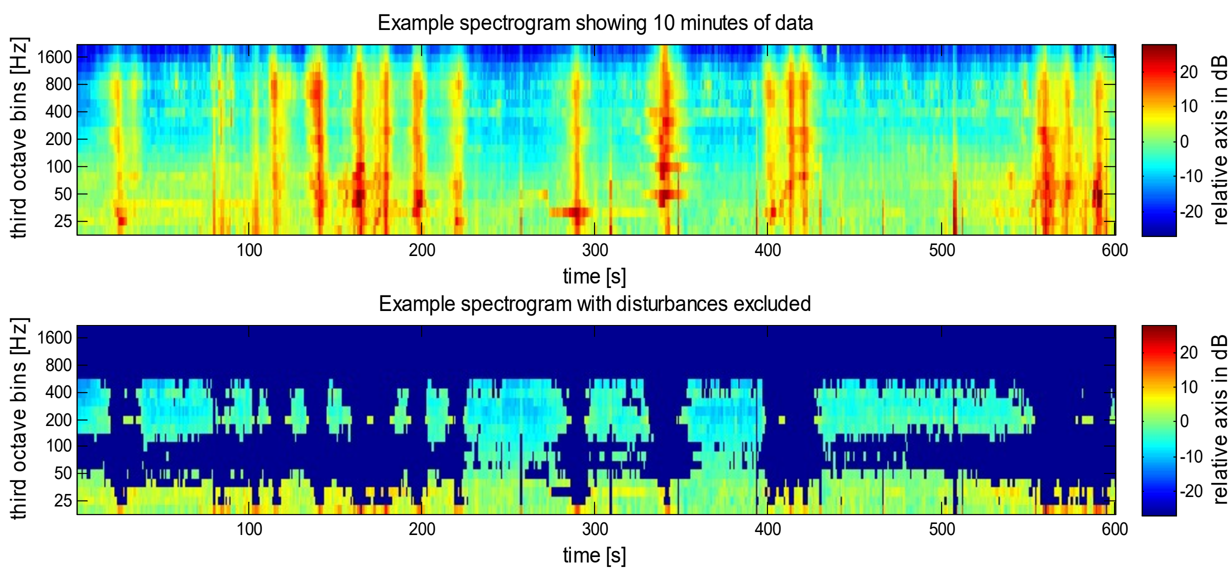


Figure 9 – Spectrogram with 10 minutes of RA data, before exclusion of disturbances (top) and after (bottom).

Next, the effect of the exclusion of local disturbances is shown for a longer period. Figure 10 shows the sound levels in the month of October 2016 for a single RA station. The black line is the original measured sound level, for the frequency bands up to 250 Hz. The blue line is excluding the local disturbances. In general, the original measurements show a rather constant daily pattern, while the corrected measurements show gradual increases and decreases of the sound levels during a number of days. The figure also shows the wind speed and direction, with some degree of correlation. But a more detailed analysis is needed to relate this effect to both the possible variations in source strengths and meteorological conditions. Then also multiple monitoring station in the RA can be used, as shown in a previous study on excluding disturbances (3).

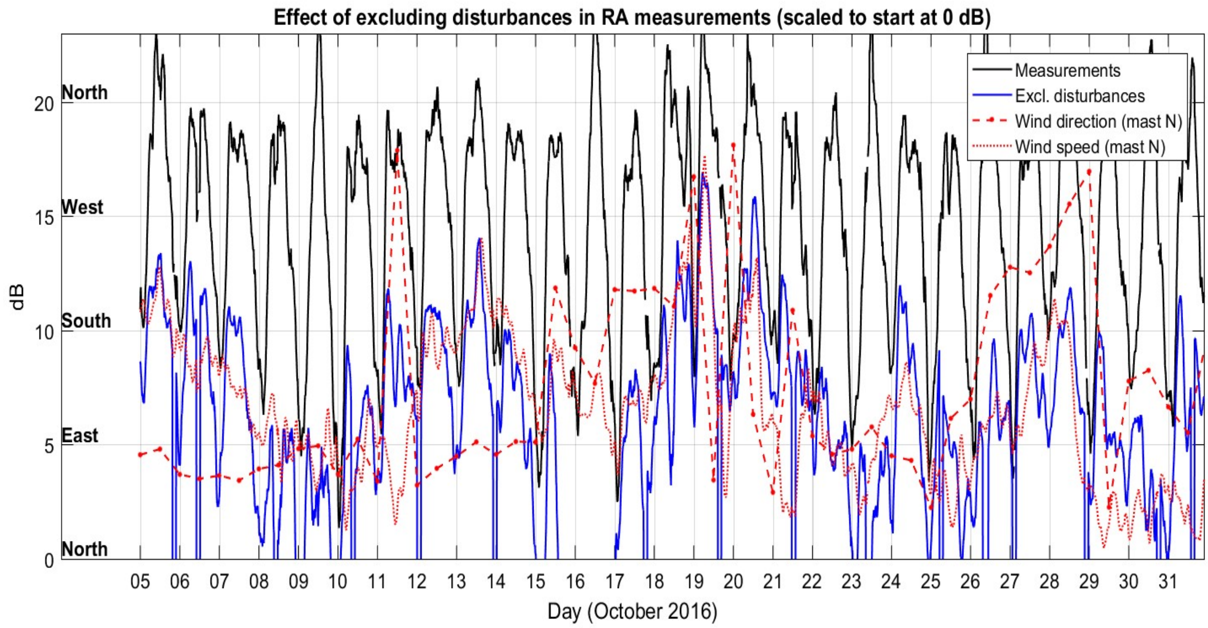


Figure 10 – Comparison of measured sound levels (10 minute averages) and sound levels after exclusion of local disturbances, using an offset to start at 0 dB.

## 5. CONCLUSIONS

A model based monitoring system for a large industrial area was described and the effects of the time-varying sound propagation were addressed. It was shown that by combining techniques for measurements and model results, it is possible to capture the complex acoustic situation to be able to relate it to complaints. The techniques, or building blocks, discussed here comprised: I) the time-varying sound propagation over an industrial area, II) the meteorologically dependent screening effect of an earth berm, III) the time-varying sound propagation towards the residential area over 12 months, and IV) the long-term monitoring results in the residential area excluding local disturbances. The combination of these techniques makes it innovative, but the large area and complex meteorology also makes it challenging. Further studies on the results are ongoing. Nevertheless, it is expected that the use of large scale monitoring, and therefore the role of time-varying sound levels as perceived in real life, will further increase.

## ACKNOWLEDGEMENTS


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