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Time varying sound propagation for a large industrial area

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ABSTRACT

The distance between noise sources at a large industrial area and a local community can be in the order of several kilometers. At such distances it may not be clear which sources are the main contributors to possible noise complaints. A long-term monitoring project is described that measures the sound sources in the industrial area and the sound in the nearby residential area. This paper focuses on the time varying sound propagation that is needed to determine the industrial source strengths and the relevance of the sources for the nearby community. Data from a meteorological model is combined with measurements from four geographically distributed meteorological masts via data assimilation. In this way the wind and temperature, as a function of height and time, between all possible source and receiver locations can be determined. Next, the corresponding sound propagation for all transfer paths is obtained near real time as these have been calculated beforehand. 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. This approach makes a comparison with registered complaints over time meaningful.

1. INTRODUCTION

In a previous project "Geluid in Beeld" (A view on sound) the industrial sound from the Europort/Maasvlakte area in the port of Rotterdam towards the city of Oostvoorne was investigated (1). The objective was to understand the occurrence of unexpected noise complaints and the complex sound propagation between the industry and Oostvoorne. For the sound propagation a detailed meteorological-acoustical model was applied. The meteorology in this area can be complex due to effect of the North Sea and a lake situated between both areas. For a selected period of time a better understanding of the occurrence of complaints and the meteorological-acoustical situation was found. The project was not intended to search for specific sources.

In this paper a long-term noise monitoring system (Geluidmeetnet Maasvlakte) is described that

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has started recently. This project was initiated by the DCMR (the environmental protection agency in the Rijnmond region), the municipality of Westvoorne (which includes Oostvoorne) and The Port of Rotterdam. The monitoring system has been developed by 4 parties: the University of Ghent, TNO, ASAsense, and Art For Millions. Besides monitoring for one year in 2016, a panel of inhabitants of Oostvoorne is providing feedback on noise coming from the monitored area. The objective is to determine what source areas in the industrial area (IA) contribute the most to the noise annoyance and/or complaints in the residential area (RA) of Oostvoorne. The monitoring system has an innovative character and during the year 2016 the analysis of the data aims at showing to what extent source areas can be indicated. It is remarked that the contributions from the industry, road and rail are within the legal noise limits.

Figure 1 shows an overview of the industrial and residential areas (IA and RA). At the right hand side the positions of 10 IA and 4 RA microphone positions are shown with blue markers. The red markers show microphone arrays and the yellow markers the positions of meteorological masts.
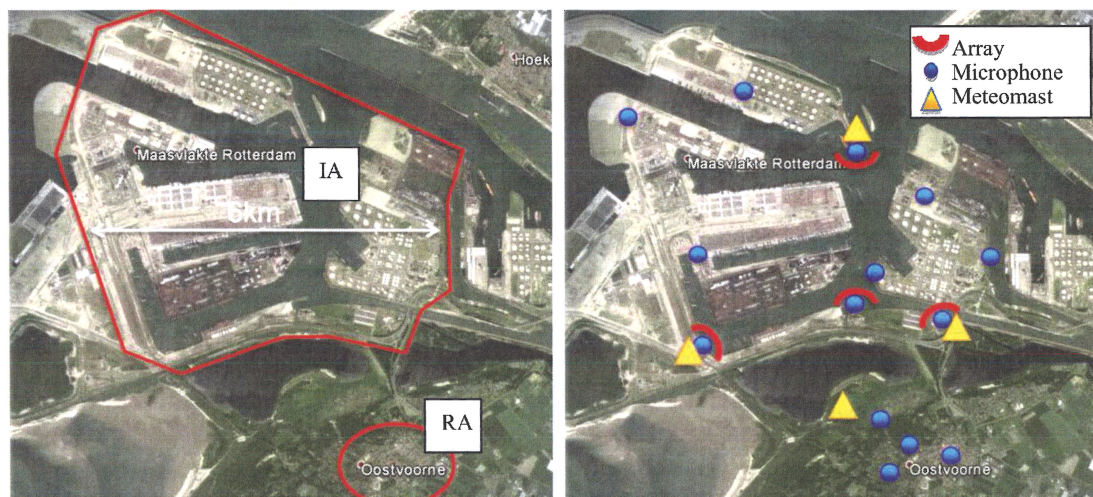

Figure 1 – Right: indication of the size of the industrial area (IA) and the distance to the residential area (RA). Left: Locations of the microphones , arrays, and meteorological masts.

In the next section the monitoring system is described in more detail. Section 3 illustrates the use of meteorological model and measurement data and the combination of both. In section 4 this data is used to be able to determine the time varying sound propagation. The conclusions are presented in section 5.

2. DESCRIPTION OF THE MONITORING SYSTEM

2.1 Arrays and microphones

The variety and complexity of industrial noise sources can be wide. Also, low frequency noise is important as the distance between the IA and the RA is in the order of several kilometers. In order to localize 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 arrays the sound can be localized (6). Figure 2 shows a photograph of an array located at the South side of the IA (other arrays: North, West, East).

Additionally, in the industrial area 10 microphones were installed at a height of 5 meters to captures the sound levels. Four of these microphones are collocated with the arrays, see left hand side of Figure 3.

At the industrial area wireless connections for the arrays, deployed on remote locations, have been set-up towards wired locations (optical fiber) a few kilometers away. These wireless connections are based on exclusive usage of the licensed spectrum in the 3.5 GHz radio band using OFDM technology with failover sustainability on site with ruggedized 3G/4G/LTE networking radio equipment for load balancing.

The noise is also monitored in the residential area with 4 monitoring posts (2,3). The center of Figure 3 shows a microphone and its hardware box connected to a lamppost. At the right hand side the

currently used large windscreen is shown. Besides the directly measured sound levels, the sound levels at these locations are also estimated with the help of the monitored sources in the industrial area. The difference is used to distinguish between the industrial related noise and other sounds in the residential area. For the monitoring of an industrial area all other sounds are not relevant and should be excluded from the analysis. This approach is an alternative compared to the audio classification sounds.

Figure 2 – The array at location South, with 40 microphones at an 50x30m area. In the center an IA microphone.

Figure 3 – An IA microphone (left), a RA microphone (middle), the 18cm applied windscreen (right).

2.2 Meteorology

As the meteorology can be complex in the area, 4 meteomasts were placed distributed over the area (see Figure 1). Three of these masts are collocated with the arrays and share both power and network connections. One mast is provided with a solar panel and a SIM card. The masts provide data each minute on temperature, humidity, pressure, rain, windspeed and direction. The wind direction and speed are measured at 10 meters height. See Figure 4 for an impression of the meteomast at the West array location. The meteomast in the North provides temperature and wind speed at several heights to better obtain the sound speed profile.

2.3 Output

Via a user interface noise emission maps (NEM) for the IA can be generated for a selected period of time. These NEM's show the sound levels in dB/m^2 and include an indication of the expected accuracy (due to combined beamforming of the arrays and the variability of the meteorology). Also, a corresponding map is made that is corrected for the sound propagation towards the residential area. The resolution of these maps is 200 x 200 meters. In this paper intermediate results for the time varying sound propagation are given. As this is an ongoing project results for the noise emission maps can be shown at a later stage.

Standard periods of time of 10 minutes are used, which can be aggregated to longer periods. With

the user interface these time frames can be selected and settings for the frequency range can be made. The sound levels are stored in one-third octave bands ranging from 25 to 630 Hz; higher frequencies are not important due to increased attenuation. Within each time frame audio fragments are stored for listening.

The user interface shows a dashboard with the actual status of the sensors and measurement data, see Figure 5. Actual spectral results for the microphones can be shown as well as wind and temperature profiles. All data is stored and backed-up with an size of several TB.

Figure 4 – At the right hand side, a 10m high meteorological mast within the West array location.
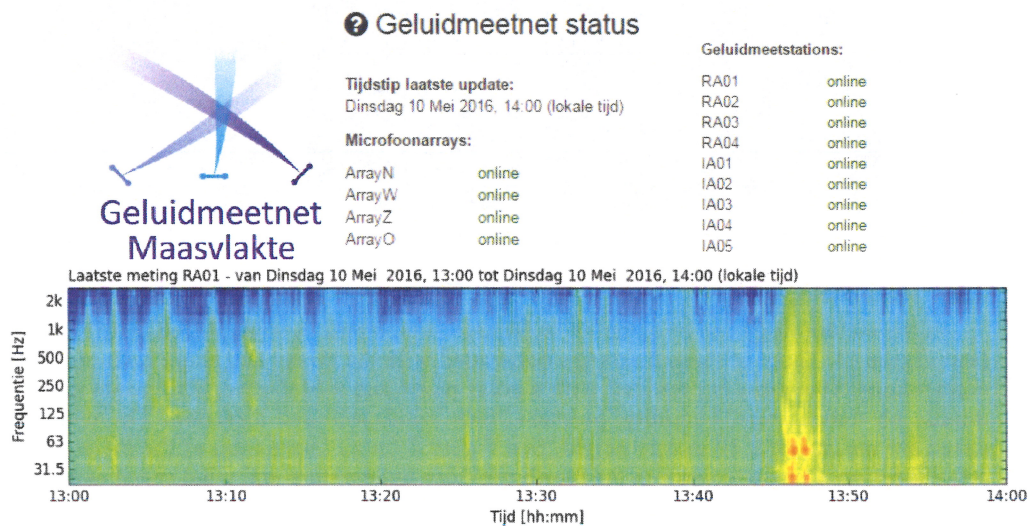

Figure 5 – Selection of data from the user-interface for "Geluidmeetnet Maasvlakte".

3. COMBINING METEOROLOGICAL DATA

In order to determine a time varying sound propagation between each 200x200 m^2 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 between 30 and 9000 meters (10 levels with a maximum of 700 meters is used). Forecast data for each hour up to 48 hours can be used. The "zero-hour" forecast data is closest to meteorological measurements.

The horizontal grid spacing is 11 by 6.5 km and relatively coarse for the IA and RA areas. Therefore additional measurement data is used from the 4 meteomasts and combined with the HiRLAM data.

For the wind speed profiles the roughness of the ground is of importance. This data is present in the HiRLAM data, but here a previously used map with a resolution of 250x250 meters has been used. Different ground types like forest, vegetation, grass, buildings, bare ground, water and sea, are used.

The meteorological data is determined with a horizontal resolution of 100x100 meters. The objective is to obtain the three-dimensional meteorological data for each 10 minutes including levels at 1.5m and 10m height. The HiRLAM data is available each hour. For this purpose interpolation and extrapolation of data is applied. In Figure 6, left hand side, an example of the wind speed at 30 meters height is shown when only the HiRLAM data is used.

Next, the data assimilation technique of "optimal interpolation" is applied to combine the HiRLAM data with the measured data.
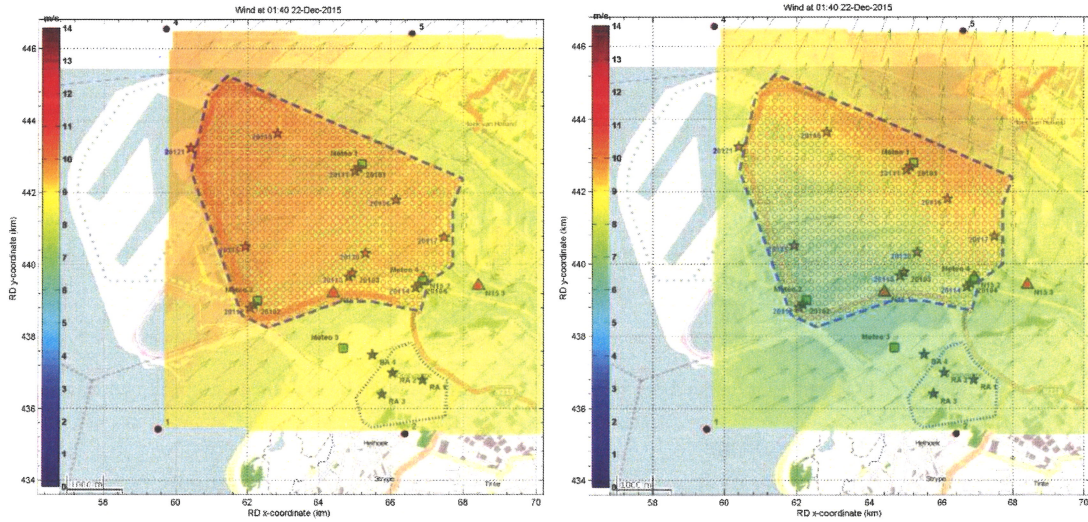

Figure 6 – Right: wind speed at 30m height based on HiRLAM data from 6 locations indicated with circles.
Left: idem, but combined with the data from 4 meteorological masts indicated with green squares.

When $y(t)$ represents the 10 minute average value of a meteorological measurement and $x^f(t)$ the corresponding value from the three-dimensional model data, i.e. the first estimate or forecast. Then the data assimilated value $x^a(t)$ at the location of the measurements is obtained via:

$$x^a(t) = x^f(t) + K\left(y(t) - x^f(t)\right) \tag{1}$$

with K the gain matrix. This matrix is a function of the uncertainties in x and y and ranges between 0 and 1. Note that the uncertainties (i.e. covariance) for x and y need to be parameterized. For x also a correlation length L is given to specify to what horizontal extent the forecast of x is corrected. The standard deviation for the model data is set to 0.5 (m/s, °C, % for humidity) with a correlation length of 2 km. For the measurements the standard deviation is 0.2.

In Figure 6, right hand side, the data assimilated results are shown. For this period of time (01:40 hours UTC) the wind speed and wind direction around the meteomasts North and West are slightly changed. A similar model based monitoring approach has been applied previously for an urban area, but then the data assimilation was applied for modelled and measured sound levels (4).

4.   TIME VARYING SOUND PROPAGATION

4.1   Sound transfer database

For each path between a source area of 200x200m^2 (more than 800) and a receiver (microphone or array in either the IA or RA) a representative sound speed profile is determined, based on the meteorological data as described in the previous section. This profile is fitted to one of 27 profiles for which the sound propagation has been calculated beforehand, see Figure 7 (5). The sound propagation results were obtained with a numerical model (PE) that takes into account, amongst others, the

refraction of sound waves. Numerous calculations were performed for different source and receiver heights and distances up to 10 km. Three different types of ground absorption were used: hard (for sand and water), soft (like grass), and very soft (like heather or forest). The sound propagation for paths with a combination of ground types is determined by weighting each of the three different propagation results with the corresponding distance. In general, a source height of 15 meters has been used for the IA. To account for scattering of sound by objects like buildings a very soft ground has been used. To estimate the uncertainty of the propagation due to the meteorology, also the two neighboring sound speed profiles were used for the sound propagation.
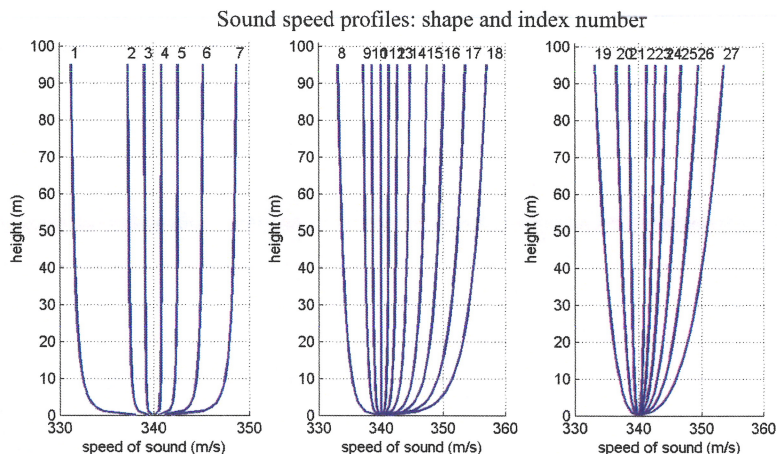

Figure 7 –Different sound speed profiles (27) as used for the database with sound propagation results.

4.2 Sound transfer results

In Figure 8 an example of the sound transfer results is shown for a 10 minute period. On the left hand side the sound attenuations are given for each source area, denoted with a red circle, towards the microphone location in the residential area (RA 2). The attenuation includes the effects of distance, air absorption, ground and meteorology. The right hand figure excludes the effect of the distance so that the effect of the ground and meteorology is more clear. For this wind direction, denoted with arrows, only a small part of the IA has a relatively higher contribution for the RA. For reasons of simplicity, the levels for all one-third octave bands have been aggregated in this figure.
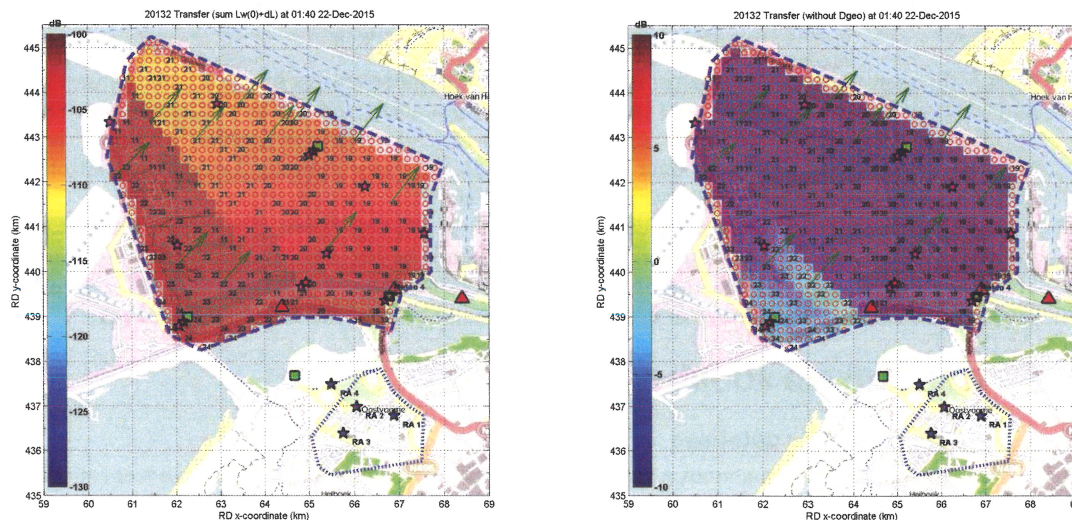

Figure 8 – Left: sound propagation results for each source area (in IA) towards the residential area (RA 2).
Right: idem, excluding the effect of distance.

To determine the noise emissions for each source area, instead of the sound immission, similar results for the sound transfer are used. Figure 9 is comparable to Figure 8, but now for each source area towards the array located in the North. As the wind direction is mainly towards this array, a much more favorable sound propagation is shown, mostly for the area's with a hard surface (i.e. water).
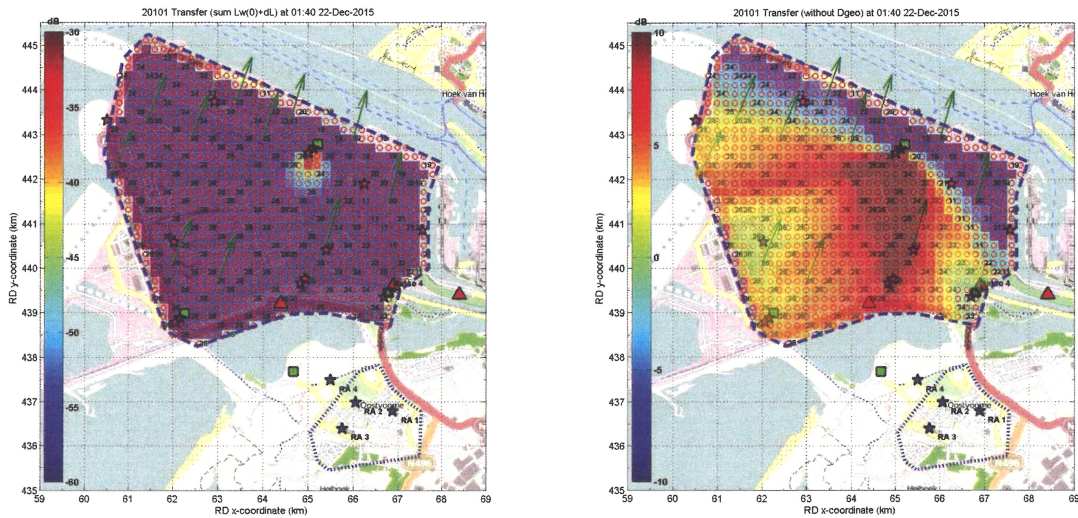

Figure 9 – Left: sound propagation results for each source area (IA) towards the array North.
Right: idem, excluding the effect of distance.

In the next figure the time varying meteorology and the sound transfer for April 2016 are shown. As a comparison, the top figure shows meteorological data obtained from a KNMI mast located North-East of the industrial area. The daily averaged wind direction is indicated with arrows. In the bottom figure meteorology data as used by the monitoring system is shown, averaged for the path between a central location in the industrial area and the residential area (RA 2). Hourly based data has been used here. The agreement between both wind speeds is fair, with somewhat higher speeds for the KNMI mast. Notice the (small) differences for the wind directions between both results.

In the bottom figure also relative sound transfer results are given, with the minimum set to 0 dB. The spectral results are aggregated (using a source without spectral variations). Due to the varying meteorological conditions the sound levels vary as much as 15 dB. Also, with a changing wind direction the sound levels can increase by 10 dB during a short period of time. The noise emission maps are corrected for this time varying sound transfer, but include also the possible varying source strengths for each source area.

5. CONCLUSIONS

An industrial noise monitoring project has been set-up for a large area that takes into account the different meteorological conditions. This paper focusses on the time varying sound propagation. The propagation is used in two ways: 1) to estimate the sound from localized sources, and 2) to estimate its contributions at the residential area a few kilometers away. A standard noise model generally uses only a constant sound propagation based on an average meteorology. By considering the time varying contribution a comparison with registered complaints over time is much more meaningful.
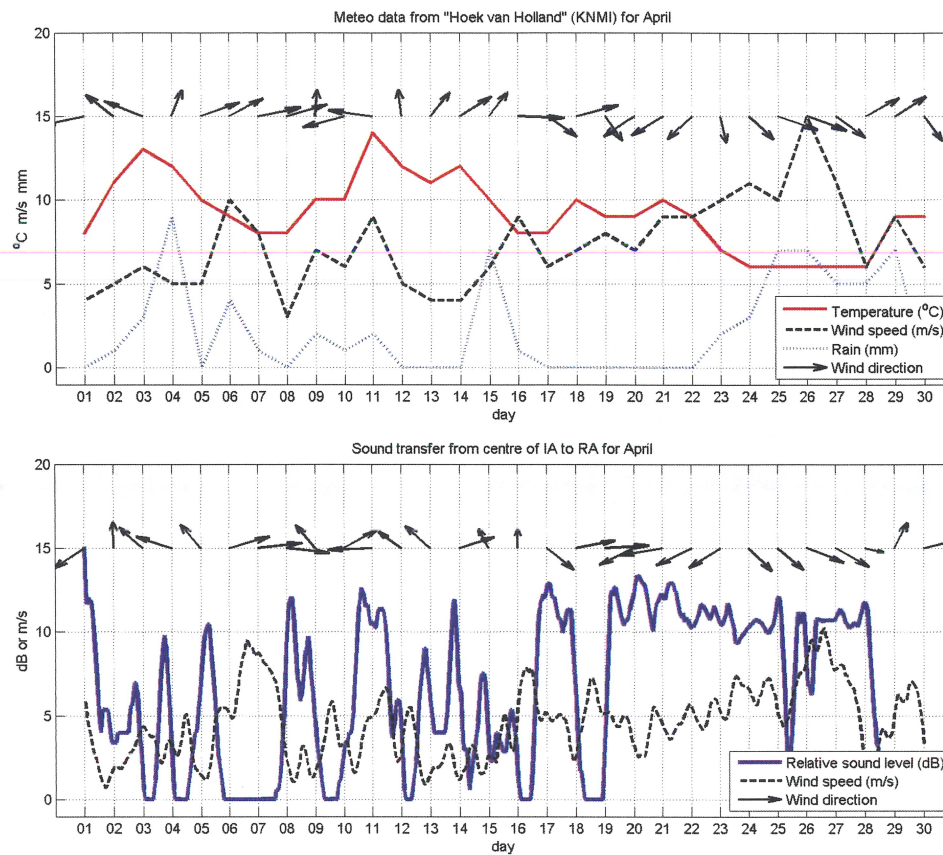
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Figure 10 – Top: meteorological data, averaged per day, from nearby KNMI mast at "Hoek van Holland".
Bottom: Relative sound levels from IA to RA for a uniform source and meteorological data as used by the monitoring system (here: hourly based).

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