

A meteorological-acoustical model: comparison with measurements

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Introduction

A meteorological-acoustical model for the prediction of long range sound propagation with meteorological effects has recently been presented [1]. This model was developed in the framework of the Dutch project ‘‘Geluid in Beeld’’ (a View on Sound) and initiated by the Council of Westvoorne, The Port of Rotterdam, the environmental protection agency DCMR and the dry bulk terminal EMO located on the industrial site of the Maasvlakte/Europort in the port of Rotterdam (The Netherlands). Annoyance caused by the industrial noise from Maasvlakte/Europort has emerged in the nearby village of Oostvoorne. This motivated the creation of the project ‘‘Geluid in Beeld’’, aiming at reducing or even preventing noise annoyance in Oostvoorne from the industrial activities. To achieve this, the scope of the project included the development of a coupled meteorological-acoustical model for the prediction of long range sound propagation. The model has been used to get a better understanding of the sound propagation from the industrial site to Oostvoorne. The meteorological model provides meteorological prediction data over the area, which are then used in the acoustic model to calculate the characteristics of the sound field along the sound propagation path, using the Parabolic Equations method.

Results of the model have been presented both for the case of sound propagation of an impulse noise and of industrial noise on a coastal area of the Maasvlakte [1].

This paper presents the work performed subsequently to validate the meteo-acoustic model.

First, the field measurements carried out on the industrial site and the propagation path are described. These measurements included meteorological measurements and acoustic measurements using a source array made of 16 loudspeakers. Measurements of the power levels of the source were performed, as well as noise level measurements at a number of locations along three sound propagation lines.

Secondly, the comparison with results from the meteo-acoustic model is addressed. Noise levels are predicted with the model for the same locations as the measurements and compared with the measurement results.

Field measurements

Measurement plan

Acoustic measurements have been performed on two source locations (location 1 and 2 in figure 1) and along 3 sound propagation lines as indicated by the green dashed lines on figure 1. The receiver locations along the 3 lines are indicated by measurement points Mptn 51, 52, 53 on measurement line 5, Mptn 21, 22, 23, 44 on measurement

line 2 and Mptn, 32 and 33 on measurement line 3. Noise levels at Mptn 44 are representative for the noise levels received in Oostvoorne. ‘‘Meteomast TNO’’ and ‘‘Meteomast VU’’ are the locations where meteorological readings were made. These are used for the comparison with the meteorological predictions of the meteo-acoustic model.

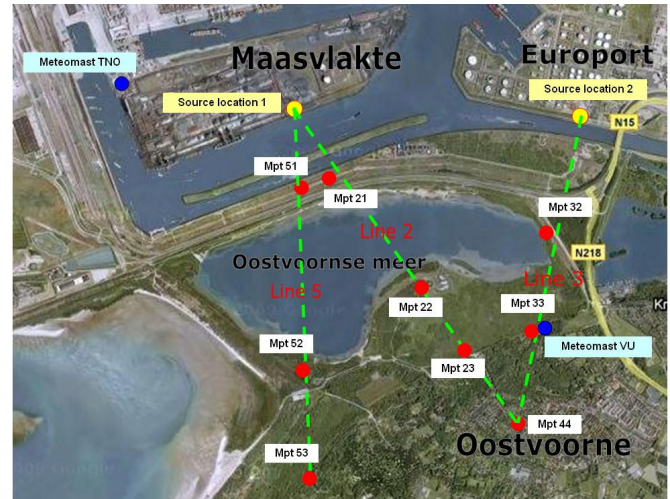


Figure 1: Aerial photograph of the measurement area.

The schedule of the noise measurements is summarized in table 1 below.

Source location	Measurement line	Measurements in 2008	Start time	End time
1	5	May 21, ‘afternoon’	13:22	16:40
2	3	May 21, ‘evening’	20:18	21:12
1	2	May 21, ‘night’	22:30	23:02
1	2	May 22, ‘afternoon’	12:50	15:28

Table 1: Measurements: source location, measurement lines and time periods.

Source measurements

While measurements provide sound pressure levels, the direct output from the meteo-acoustic model is the excess attenuation.

Both parameters are bound by relation (1):

$$L_p = L_w - 10 \log(4\pi r^2) - A_{\text{air}}(r) - A_{\text{excess}} \quad [\text{dB}] \quad (1)$$

L_p is the sound pressure level at the receiver location, L_w is the sound power level of the source, A_{excess} is the excess attenuation (due to atmospheric effects, barriers, ground effects, etc...). A_{air} is the attenuation due to air absorption calculated according to ISO 9613-1 [2].

For the later comparison exercise, it is necessary to work with the same parameter, the sound pressure level or the excess attenuation.

The determination of the source power levels will allow calculating one, knowing the other.

An array of 16 loudspeakers generating white noise was used as noise source during the measurements. (See figure 2).

Measurements at 20 m from the source were performed during each set of measurements as described in table 1 and were used to determine the power levels of the source. These were front measurements at 2.2 m and 7.0 m above ground and a lateral measurement at 2.2 m above ground and a horizontal angle of 35° with the source axis.



Figure 2: Source array used for the measurements.

Taking into account the dimensions of the source (2 m x 5.5 m), the measuring distance of 20 m was chosen to neglect all other effects but ground reflection, thus facilitate the power level calculation. This allows the assumption of a point source for calculation in the case of sound propagation in a homogenous atmosphere above a ground surface.

Based on this, the source power levels could be derived from formula (1) where, A_{excess} is simply the attenuation of a spherical acoustic wave propagating over ground.

Figure 3 shows the average SPL spectra measured at 20 m distance from source position 1. Background noise levels are also shown.

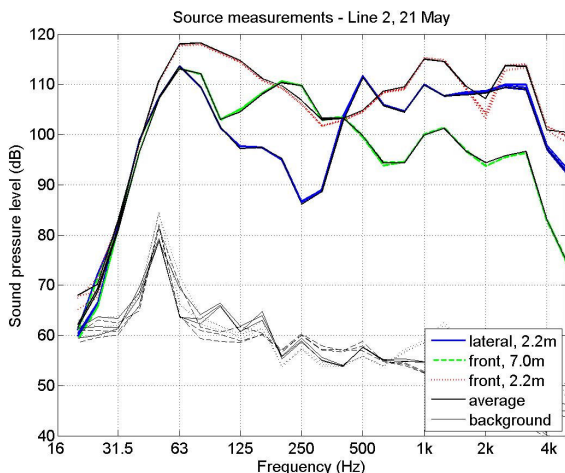


Figure 3: Measured SPL at 20 m from the source for line 2.

The ground attenuation has been calculated for two flow resistivities, $\sigma = 500 \text{ kPa.s.m}^{-2}$ and $\sigma = 100 \text{ kPa.s.m}^{-2}$. These correspond to the ground types at position 1 and 2 respectively.

Figure 4 shows the calculated ground attenuation at source position 1.

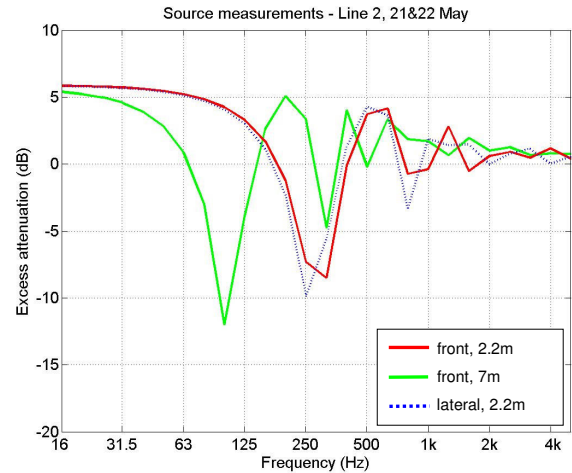


Figure 4: Calculated ground attenuation at source position 1 (receiver at 20 m from source, $\sigma = 500 \text{ kPa.s.m}^{-2}$).

The average power levels for the front and lateral situations at the two measurement locations are shown in figure 5. At a distance from the source, fluctuations found between the front and lateral measurements are neglected to obtain a flat source response. For the next calculations, a source power level of 150 dB in the frequency range 63 Hz-4 kHz will be applied. The dotted line referred to as 'distant' in figure 5 illustrates this.

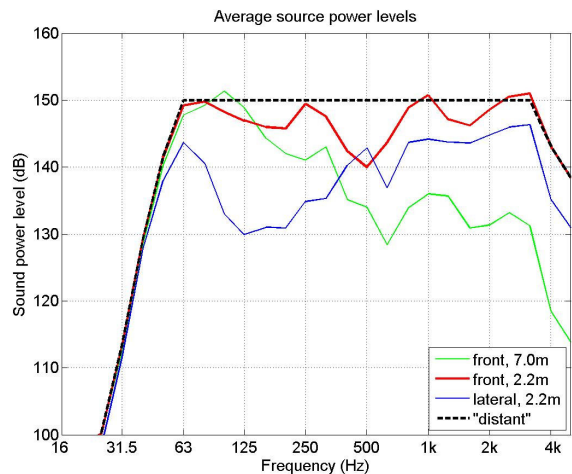


Figure 5: Calculated source power levels.

Comparison with model results

Meteorological predictions

Meteorological readings were collected continuously on the days of measurements at the two locations indicated as TNO and VU on figure 6 and monitored respectively by TNO and the VU (VU University Amsterdam). Figure 6 shows the topology of the area built in the meteo-acoustic model.

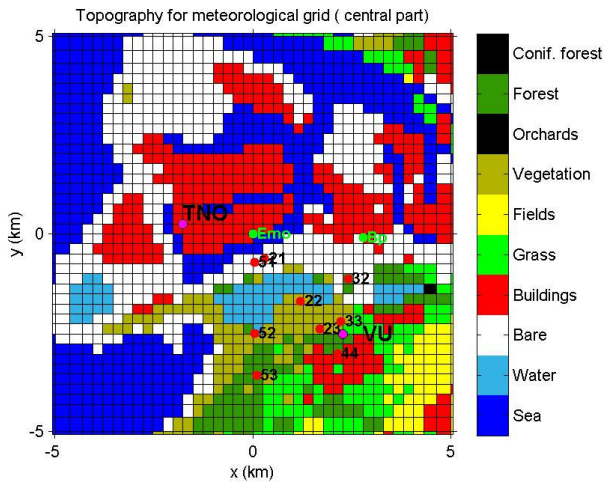


Figure 6: Topology of meteo-acoustic model.

The meteorological data measured at different heights from 0 m to 10 m were the temperature, relative humidity, wind direction and wind speed. Data were logged every minute.

In figures 7 a/b/c, the meteorological measurements are compared with the meteorological data predicted by the meteo-acoustic model for the same period.

Some differences can be observed, however, predicted data fit well with the measured data and evolution trends of the predictions follow the measurements.

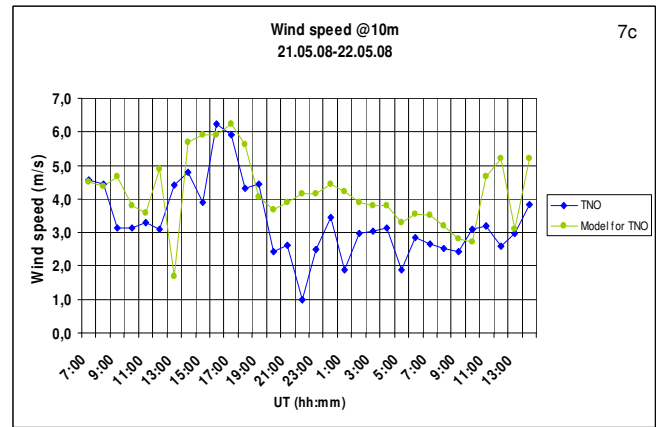
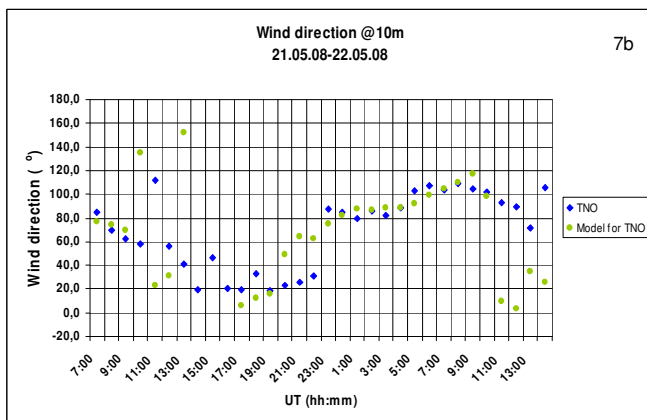
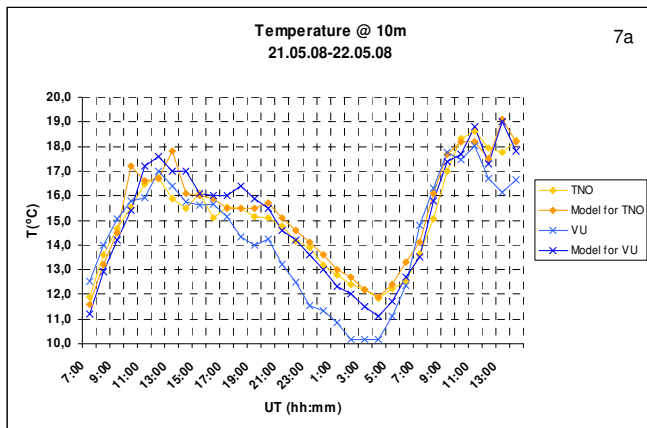


Figure 7a, b and c: Meteorological data - comparison of model results with measurements. a: temperature, b: wind direction, c: wind speed.

Influence of excess attenuation

To illustrate the contribution of the excess attenuation to the total sound pressure level at a receiver location, figure 8 shows the noise measurement results at location 21 (680 m from the source, 5 m above ground). The sound power levels corrected for the attenuation due to air absorption and the geometrical spreading *only* are also plotted and represented by the black solid line. 150 dB power levels at all frequencies were used as calculated previously.

The hatched area in blue corresponds to the difference between the measurements and the sound power levels corrected for air absorption and geometrical spreading. This shows that the rest of the sound attenuation along the propagation path is provided by the excess attenuation, as in formula (1). A_{excess} hence has a significant influence on the sound propagation.

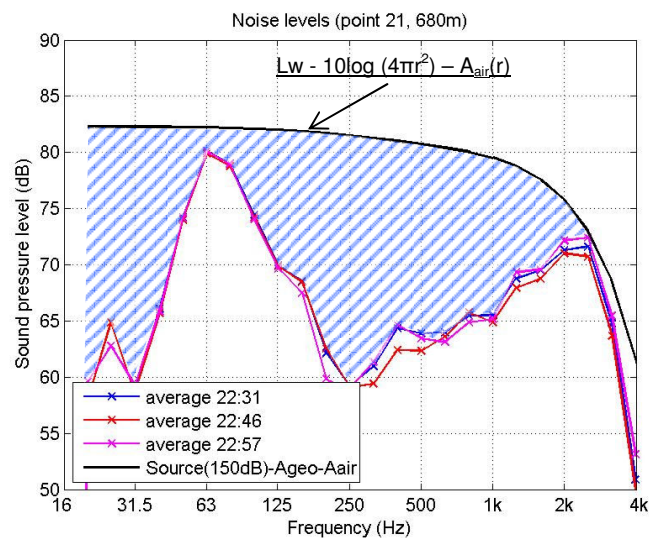


Figure 8: Significance of excess attenuation on long range sound propagation.

Acoustic prediction

Meteorological data previously predicted by the meteorological model were used to calculate the excess attenuation, using PE calculations.

Ground characteristics were also defined in terms of flow resistivity.

Calculations were made for all three lines 2, 3 and 5, at different times within the corresponding measurement periods. As an example a number of results obtained along line 2 are presented.

For the frequency of 63 Hz figure 9 shows the calculated excess attenuation along line 2 at 20.00 UT.

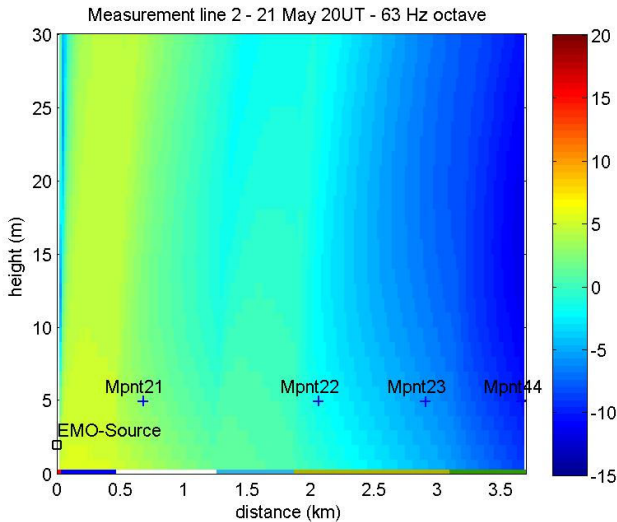


Figure 9: Predicted excess attenuation along line 2 at 20.00 UT for 63Hz.

The predicted A_{excess} spectra at location 21 are shown in figure 10 and are compared to the A_{excess} from the measurements.

In figure 11, predicted SPLs at location 23 are compared with the measurements at that position. Predicted SPL spectra have been calculated using formula (1) and sound power levels of 150 dB at all frequencies.

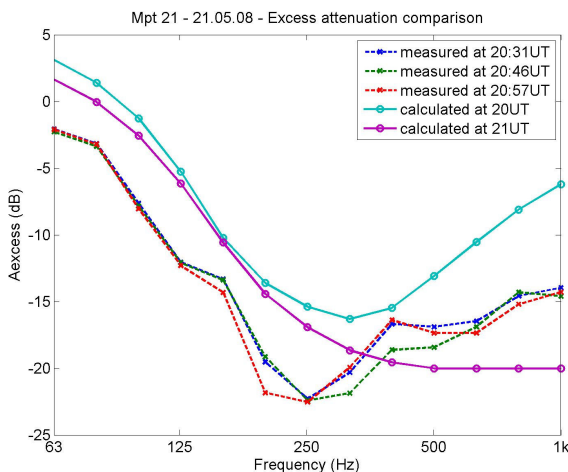


Figure 10: Predicted and measured excess attenuation spectra at location 21 on line 2.

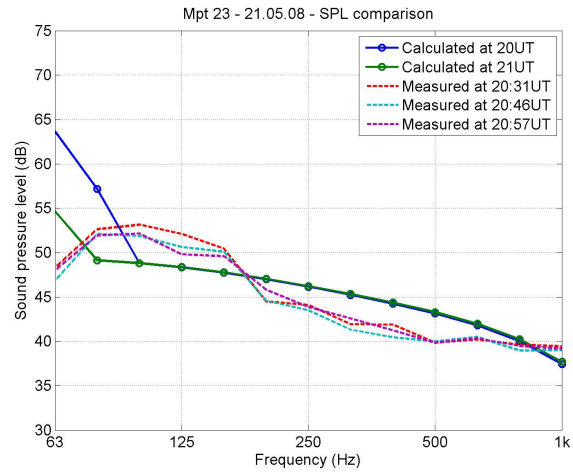


Figure 11: Predicted and measured SPL spectra at location 23 on line 2.

Discrepancies that can be observed between the predicted and measured data can be explained by the uncertainty on the meteorological predictions and on the assumptions made on the source power levels. However, predicted results show a satisfactory degree of agreement considering the large source-to-receiver distances in the calculations. Results at point 22, 23 and 44 also showed good agreement with the measurements, with generally 5 dB or less difference.

Conclusion

Results of the meteo-acoustic model have been compared to measurement in two ways. Firstly, *meteorological* measurements were compared with prediction results from the model. Secondly, *acoustic* predictions have been made using the meteorological output data of the model and then compared with the results of the acoustic measurements made at locations between the source position and Oostvoorne. In both cases, the meteo-acoustic model provided good agreement with the measurements.

The next work with the meteo-acoustic model will focus on the investigation of a relation between noise complaints in Oostvoorne and the behaviour of meteorological and acoustic parameters during complaint periods.

In the future, the findings of this study would allow using the meteo-acoustic model to foresee possible complaints and take preventive measures or find solutions to reduce or even prevent noise annoyance from the Maasvlakte/Europort in Oostvoorne.

References

- [1] Sound propagation in areas with a complex meteorology: a meteorological-acoustical model, F. van der Eerden and F. van den Berg, Acoustics08, Paris, June-July 2008
- [2] Computational atmospheric acoustics, Erik M Salomons. Kluwer, Dordrecht, 2001