Sound propagation in areas with a complex meteorology: a meteorological-acoustical model

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Long range sound propagation is largely affected by the vertical wind and temperature gradients. In areas where the meteorology can be complex, such as coastal areas, islands, and lake districts, the gradients usually vary as a function of the horizontal distance. As a result the sound propagation in these areas cannot be calculated with "standard" acoustic models, such as the ISO 9613 or Harmonoise engineering model.
By using a combination of an advanced meso-scale meteorological model and an acoustical model, that incorporates horizontal and vertical meteorological variations, long range sound propagation in such complex areas is calculated. In this paper we present two applications of this hybrid meteorological-acoustical calculation scheme: i) propagation of impulse noise in a coastal area, and ii) propagation of industrial noise in a rural area with a lake. For the coastal area sound level contours have been calculated as a function of the meteorology for an entire year. For the lake area the effect of the lake on the sound propagation is demonstrated.

1 Introduction

The meteorological situation near coastal areas, islands and lake districts can be rather complex due to large differences between the surface temperature of water and land. In order to calculate the sound propagation over distances ranging from 1 to 15 kilometers, a detailed description of the wind and temperature profile along the sound propagation path is needed. For that purpose a coupling has been made between a meteorological meso-scale model and a sound propagation model. The meteorological model employs data from a numerical weather forecast system (HiRLAM).

Using these coupled models two different applications can be realized. By using historical weather data for over a year, long-term averaged sound levels and contours can be calculated. The coupled models can also be used to produce a 'noise forecast', based on weather forecast data from HiRLAM.

In section 2 the meteorological-acoustical model will be highlighted. In section 3 and 4 two applications of this meteorological-acoustical model will be presented.

For the Netherlands Ministry of Defense, the Directorate for Spatial Planning, Environment and Real Estate Policy, long-term averaged sound levels have been calculated around a training facility near the coast. These levels are based on the calculated sound propagation around the facility for 365 days at 6 different times per day (see section 3).

Within the Dutch project "Geluid in Beeld" (A view on sound), the propagation of industrial sound on the Maasvlakte area towards the city of Oostvoorne is investigated (see section 4). This project was initiated by: The Port of Rotterdam, DCMR and EMO.

2 Meteorological-acoustical model

The structure of the meteorological-acoustical model is depicted in Figure 1. The meteorological model uses HiRLAM data (High Resolution Limited Area Model). At various meteorological institutes, including the Royal Netherlands Meteorological Institute (KNMI), the HiRLAM forecast system is used in routine weather forecasting. The horizontal grid spacing is 11 km, and encompasses the east coast of North America, the Sahara, The Ural and the North Pole. The vertical grid consists of 60 layers, ranging from 30m to 30km.

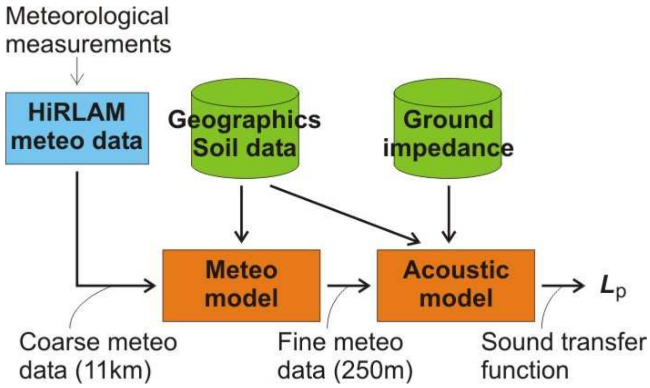

Figure 1. Structure of the meteorological-acoustical model.

The *meteorological model* was originally developed to simulate sea-breeze phenomena in a tidal area. It is a three-dimensional meso-scale meteorological model developed by Meesters of the Faculty of Earth Sciences from the VU University of Amsterdam [1].

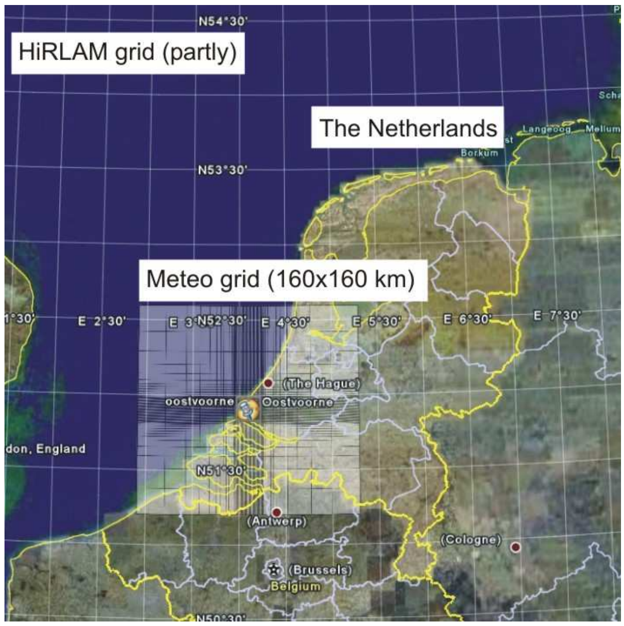

Figure 2. Overview of HiRLAM grid and meteorological model grid (centered around Oostvoorne).

The horizontal grid of the meteorological model consists of 64x64 cells and has an area of 160x160km (see Figure 2).

A staggered grid is used having a minimum distance of 250 to 500m between grid points in the centre of the grid. The density of the grid decreases towards the boundary of the grid. The model calculates the temperature, wind speed and humidity. A detailed treatment of soil and vegetation has been built in. Also, differences in solar radiation and vegetation characteristics for the time of the year are taken into account. The time step of the model decreases with increasing wind speed. For the Defense application also the influence of the tide is taken into account.

In Figure 3 HiRLAM data for the temperature at a low level is shown (10 July 2007 at night). It can be seen that the resolution of the data is too coarse to take into account the effects of islands and lakes.

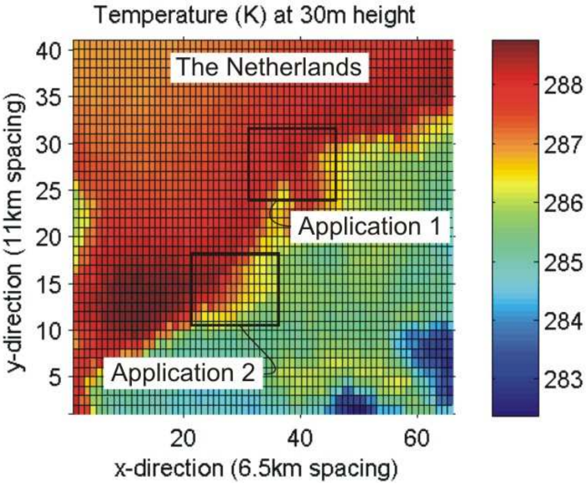

Figure 3. Temperature results for HiRLAM data (10 July 2007 at night).

Figure 4 shows details of the surface types as used for the meteorological model, for application 2. With a grid spacing of 250m the details of water-land crossings can be clearly seen. Also indicated is a line for which sound propagation calculations have been performed.

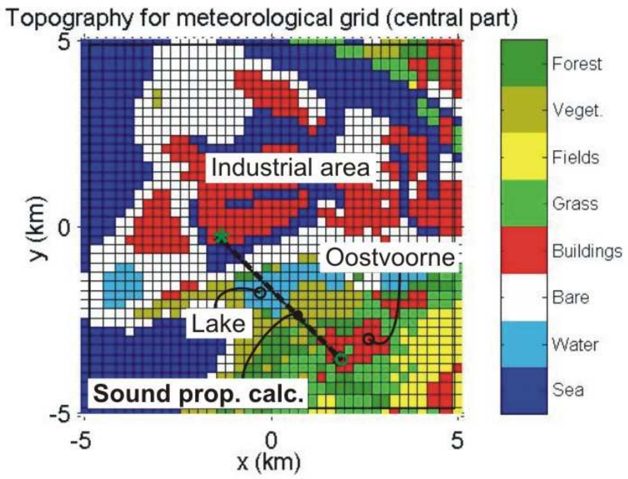

Figure 4. Central part of the topography for the meteorological model (Application 2).

For the *acoustical model* the 'Greens Function PE-model' is used [2]. The sound propagation is calculated along a horizontal line. In order to do so, at each grid point the effective sound speed is applied. The effective sound speed takes into account the temperature, the wind and the wind direction as calculated with the meteorological model. A logarithmic interpolation scheme has been used for the first vertical 10m. Figure 5 shows the results for the temperature and wind velocity obtained with the meteorological model along the propagation line, as well as the resulting effective speed of sound as a function of distance and height. The wind direction is north-west. The line for the sound propagation is shown in Figure 4, the corresponding ground types are also indicated in Figure 5.

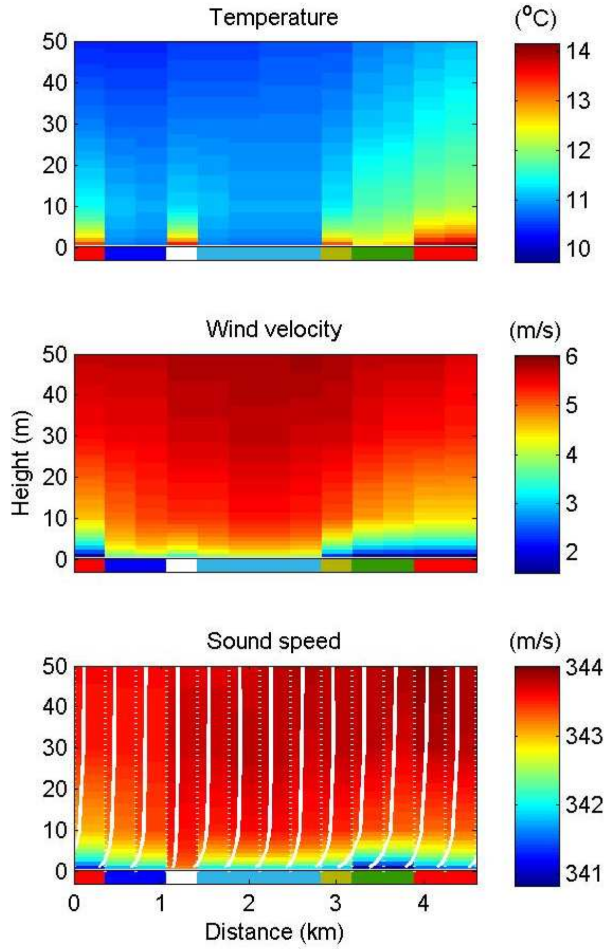

Figure 5. Example of temperature, wind velocity and resulting sound speed as a function of distance and height along the line for a sound propagation calculation.

The sound propagation over water is also influenced by the roughness of the surface due to waves. Sound propagation over a rough surface results in lower sound levels at the receiver positions, because part of the sound energy is reflected with relatively large elevation angles [3]. This was also taken into account for application 1.

3 Application 1: long-term averaged sound levels

The objective of this application is to estimate the long-term averaged sound exposure level due to activities on a Dutch military training facility which is located on an island. In Figure 6 the center of the meteorological grid is shown. The long-term averaged sound level contours are derived from 9 directions around the island. The sound propagation has been calculated for the meteorological situations of the year 2003.

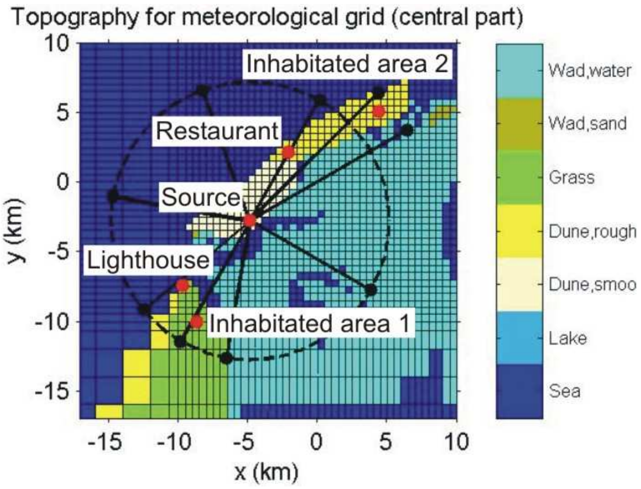

Figure 6. Central part of the topography for the meteorological model (Application 1).

We investigated indicatively how much the meteorological situation in the year 2003 deviates on average from the last 20 years. It was found that if not only the year 2003, but a larger period was used to estimate a long-term averaged level, this should result in differences of only a few tenths of a dB. Therefore it was concluded that the year 2003 could be used as a reference year to take into account different meteorological situations which can occur over years. For four points in time during the day-period we calculated for each day of the year 2003 the sound exposure level for impulse sounds. We used HiRLAM data from the year 2003.

For all results the A- and C-weighted levels are determined. Based on these two measures a contribution to the long-term averaged sound level can be determined [4].

Figure 7 shows the A-weighted levels as a function of the distance towards the inhabitated area 1 in the south. The averaged level for 2003 is based on 365 x 4 = 1424 meteorological situations (for the day time), see also [5].

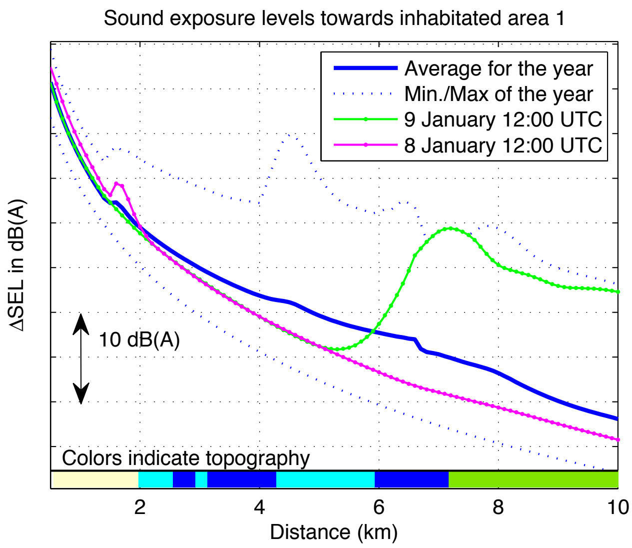

Figure 7. Averaged A-weighted sound pressure levels and levels for the meteorological situation at Januari 9th and 8th in the direction of inhabitated area 1.

The green line represents an interesting situation for the sound propagation. The corresponding effective speed of sound profiles, following from the wind- and temperature profiles, is shown in Figure 8. Figure 9 shows the resulting curved sound rays and Figure 10 the relative sound level, i.e. the excess attenuation (without the effect of geometric spreading and air absorption), as calculated with the acoustical model.

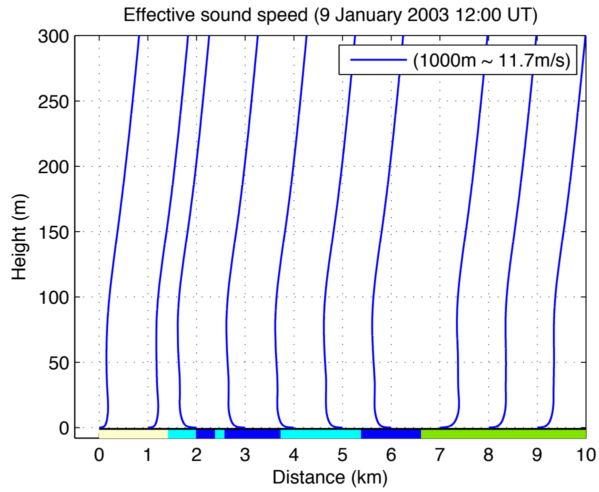

Figure 8. Effective speed of sound as a function of distance and height.

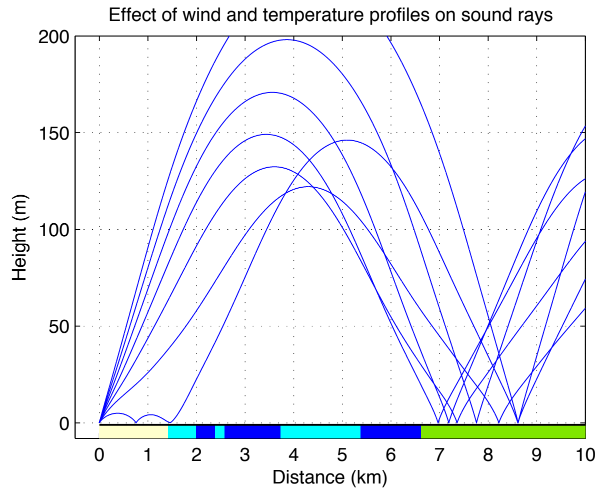

Figure 9. Curved sound rays due to the speed of sound profiles as shown in Figure 8.

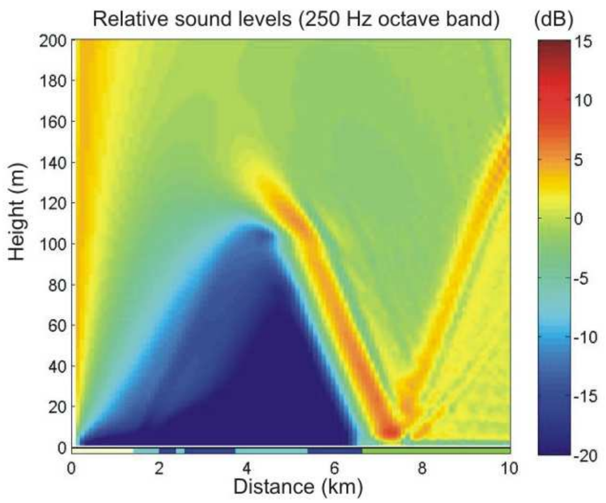

Figure 10. Results of the acoustical model, i.e. excess attenuation levels, for the 250 Hz octave band for the profiles as shown in Figure 8.

Rating sound level contours, based on the number of impulses and the averaged A-weighted sound levels, for several sources and source heights are shown in Figure 11. The contours are based on more than 100,000 meteorological-acoustical calculations.

For this area the actual meteorological conditions are taken into account, such as the stronger winds in this area, compared to the Dutch average situation. Also, the prevailing west wind is accounted for.

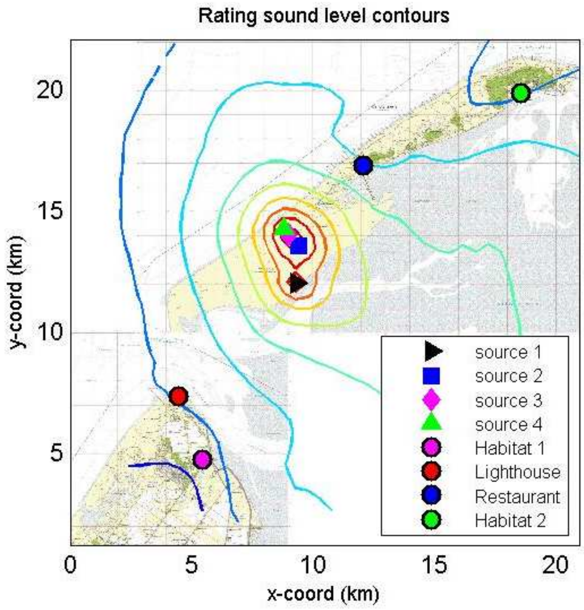

Figure 11. Rating sound level contours around a military training facility, based on the number of impulses and the A-weighted sound levels.

By taking into account the actual meteorological conditions it can be seen that the *short-time averaged* (e.g. over one hour) sound levels can vary through the year as much as 20 dB, see Figure 7. To determine the sound exposure levels the meteorological-acoustical model provides a more reliable solution than standard acoustical models.

4 Application 2: industrial sound propagation

The objective of this running project is to obtain a better understanding of the relationship between the emitted industrial sounds, the sound propagation and the reported complaints at the surrounding community. The meteorological-acoustical model serves as an investigatory tool.

As an example, Figure 12 shows the wind speed at 10m height obtained from the meteorological model, at 25 February 2007. Depicted is the same area as shown in Figure 4. Clearly, the wind speeds are higher above the seawater and above the lake.

In the following figures the effect of the temperature profile on the sound propagation is demonstrated.

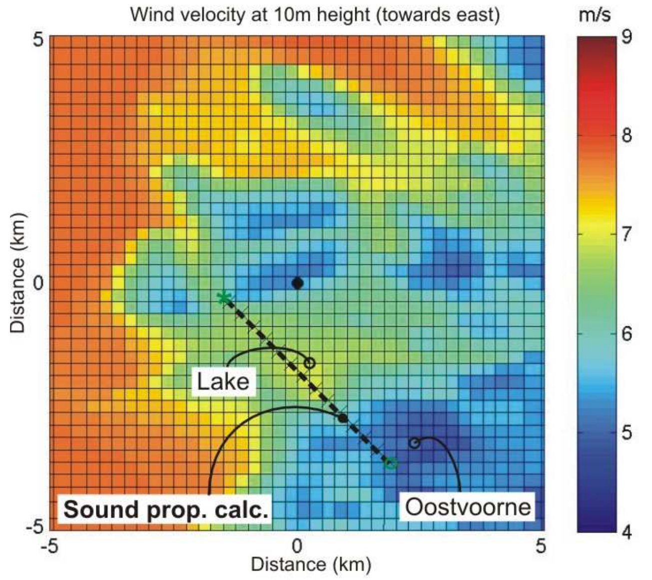

Figure 12. Wind velocity for a coastal area and over a lake. Results from the meteorological model, see also Figure 4.

The temperature and the wind velocity as a function of the height is shown for 5 April and 25 February 2007, see Figure 13. Reespectively, at day-time at 12:00 UT and in the evening at 21:00 UT. For both days the wind direction is north-west.

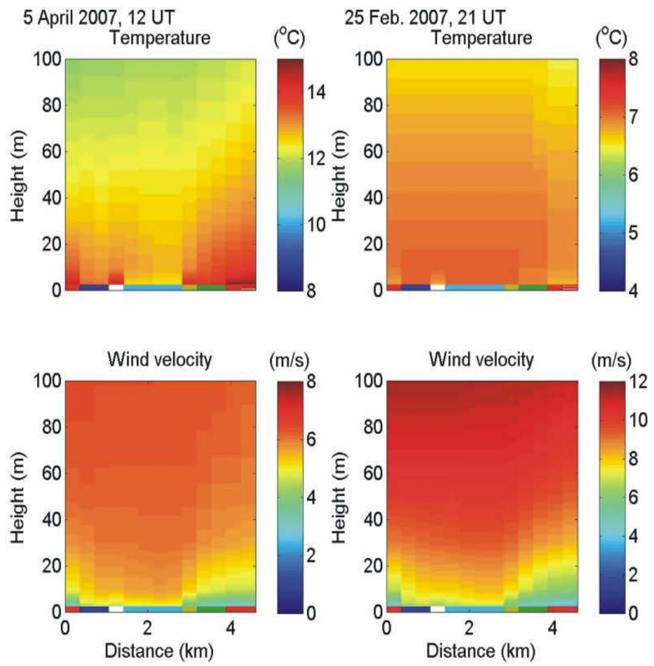

Figure 13. Temperature and wind velocity profiles along a propagation line calculated with the meteorological model, see Figure 4.

The resulting sound speeds are shown in Figure 14. As a result of the decreasing temperature with height in April, the sound speed is much lower at larger altitudes. Whereas the relatively stable temperature situation for the evening in February results in a favourable sound propagation condition. Figure 15 depicts the corresponding relative sound levels, i.e. the excess attenuation without the effect of geometric spreading and air absorption.

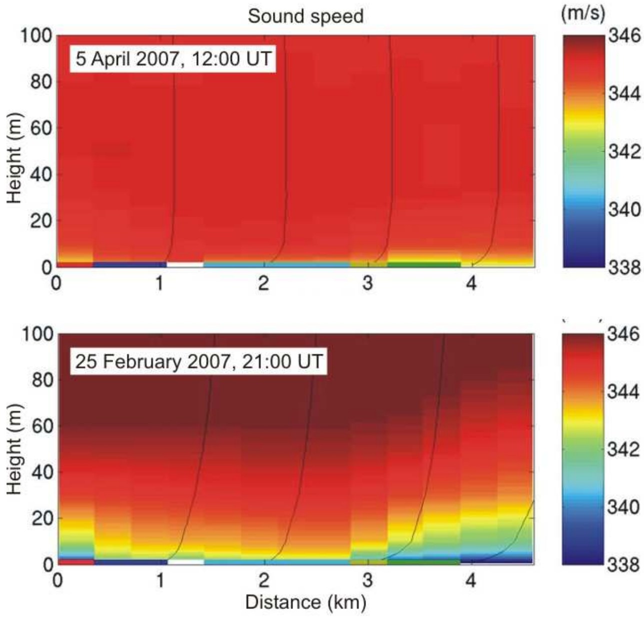

Figure 14. Effective sound speed, calculated with the meteorological model.

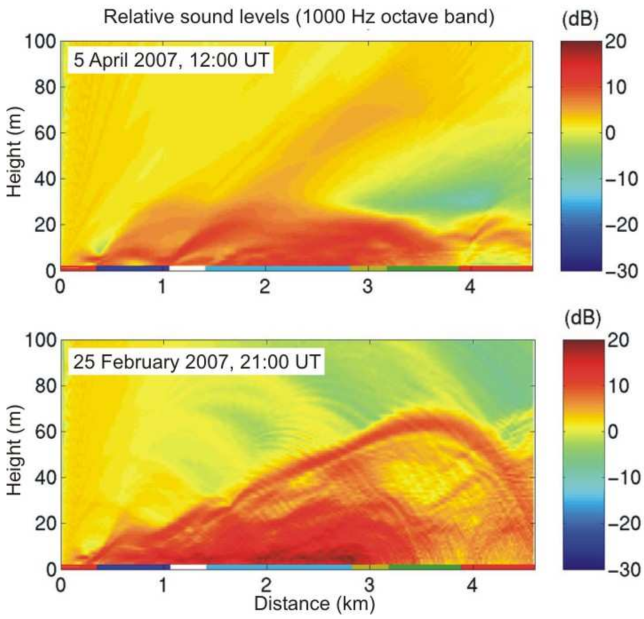

Figure 15. Calculated relative sound levels, without air absorption and geometric spreading.

The presented results are in line with the expectations. However, the model provides a mean to determine the sound propagation conditions and the sound levels for many days as well as for several periods of the day. Also, the effect of measures can be calculated in advance. Extensive measurements are planned by the participating partners to validate this application of the meteorological-acoustical model.

5 Conclusion

The combination of a meso-scale meteorological model and an acoustical model results in a powerful tool to calculate long range sound propagation in areas where the meteorology is complex. Further, the detailed forecasts on wind and temperature profiles enable the forecast of sound levels. The models have been applied for two situations where horizontal and vertical meteorological variations frequently occur: for a military training facility on an island and for the propagation of industrial sound over a lake in a coastal area.

Acknowledgments

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References

[1] A.G.C.A. Meesters, “Thermally-forced meso-scale circulations in tidal areas”, PhD Vrije Universiteit Amsterdam (1991)

[2] K.E. Gilbert, X. Di, “A fast Green’s function method for one-way sound propagation in the atmosphere” J. Acoust. Soc. Am. 94, 2343-2352 (1993)

[3] E.M. Salomons, “Computational atmospheric acoustics”, Kluwer academic Publishers, ISBN 0-7923-7161-5 (2001)

[4] J. Vos, “On the annoyance caused by impulse sounds produced by small, medium-large, and large firearms”, J. Acoust. Soc. Am. 109(1), 244-253 (2001)

[5] Frank van den Berg, Frits van der Eerden, “Calculating noise levels around military shooting ranges using a hybrid meteorological-acoustical model”, Inter-Noise proceedings, Honolulu, USA (2006)