Excess attenuation of sound due to the atmospheric influence on sound propagation

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Introduction

The improvement of forecasting of sound immission including atmospheric and ground effects is an important task of the environmental protection particular near inhabited areas. In Germany a lot of guidelines exist to produce a prediction for the sound immission. VDI-guideline 2714 [1] is used to determine the meteorological and ground attenuation. The excess attenuation calculated with this guideline is always noise reducing. But measurements and sound propagation models show differences to this result. There are meteorological situations where the sound immission increases because of the coupled influences of the vertical gradients of air temperature and wind vector.

Sound propagation model SMART

Effects of sound-ray refraction in the atmosphere and sound-ray reflection at the sound-hard surface on the sound immission are investigated by the model SMART (Sound propagation model using ray-tracing). The two-dimensional sound model calculates the sound-ray paths between a point source and a receiver. In contrast to the usual application of the refraction law to the normal of the wave, the presented model uses a refraction law directly developed for the sound-ray propagation inside a moving, stratified medium [2]. The direction and the amount of the refraction of sound rays are dependent on the vertical gradients of air temperature, wind direction and wind velocity. In the case of a temperature inversion the sound rays are curved down to the ground. This effect increases in the downwind direction so that the sound signals can received over long distances. If the influence of vertical gradients of the wind velocity is great, the sound rays are refracted upward in the upwind direction.

In this case a region exists where no sound rays arrive. This region is called the shadow region.

The calculated sound rays are used to determine the change of the sound intensity level at the immission height. It is only dependent on the cross-section of a ray-tube in a reference distance and an actually distance to the sound source [3]. The difference between attenuations of sound for a refracting atmosphere and a non-refracting atmosphere leads to the excess attenuation of sound caused by sound reflections of ground surface refractions of the sound rays due to existing vertical gradients of air temperature and the wind vector.

As before mentioned, the input data for SMART are measured vertical wind velocity, wind direction and air temperature profiles. They were interpolated between surface and height of 50 meters with a resolution of 0.1 meter. The profiles of wind velocity and air temperature are logarithmically fitted. The wind direction is constant with increasing height.

Figure 1 shows the excess attenuation of sound caused by a sound-hard surface for a selected meteorological vertical profile with a decreasing air temperature and an increasing wind velocity with height.

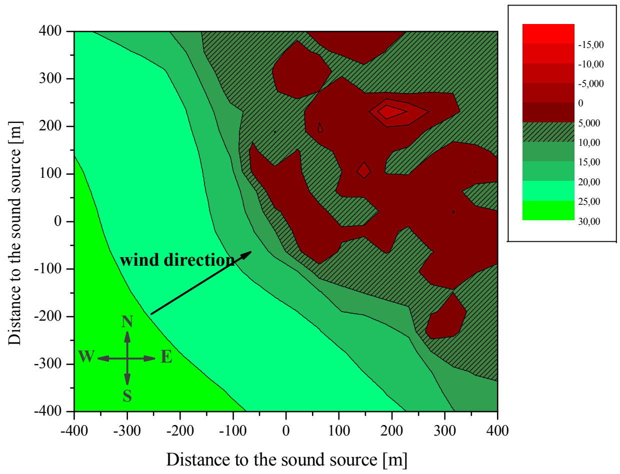

Figure 1: Excess attenuation in dB caused by perfectly reflecting surface influence on the sound propagation in comparison to a completely absorbing surface. Positive values: decreasing sound immission, negative values: increasing sound immission, zero: no surface influence

The sound source is placed in P (0, 0).

The sound-rays are reflected at the sound-hard ground in the downwind direction. This leads to increasing sound immission (negative values) in comparison to a completely absorbing ground. In the upwind direction the sound-rays are refracted upward. This causes a reducing of the sound immission.

Acoustic travel-time tomography

The method of acoustic travel-time tomography uses the horizontal sound propagation in the atmospheric surface layer [4]. Here this method is used to measure the travel time of sound signals and the relative sound amplitude. Each sound signal propagating through the atmosphere has another travel time in dependence on the atmospheric stratification, the distance between source and receiver and the sound propagation direction. With the knowledge of the travel times the relative sound amplitudes can be allocated to the belonging sound paths. With the assumption of a sound propagation with constant frequency the averaged sound pressures and sound pressure levels can be calculated. The difference between the sound levels of two receivers, which are placed in the same direction but in other distances to the sound source, leads to the attenuation of sound. The difference to attenuation, which is caused by the geometrical spreading of sound, is the excess attenuation due to all influences (e.g. refraction, reflection, turbulence).

Comparison between the measured and the modelled data

The excess attenuation of sound caused by the refraction of sound-rays propagating through a vertically stratified atmosphere was experimentally and numerically estimated to quantify the correlation between the acoustic and meteorological parameters. Figure 2 shows the course of the wind direction and of the vertical gradients of wind velocity and air temperature over the measuring period on the 06.07.2002 at the Boundary Layer test site Falkenberg (German Weather Service).

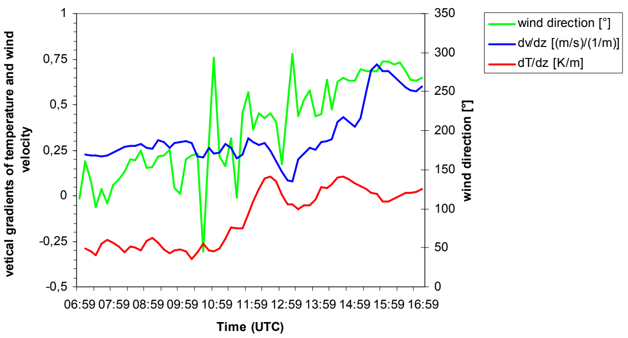

Figure 2: course of meteorological wind direction (green), vertical gradients of temperature (red) and wind velocity (blue) during measuring period

There are two time periods showing an air temperature inversion (about 12:30 UTC and 15:00 UTC). The wind direction turns from 120° to about 280° in measuring period. The excess attenuation determined by using the measuring values of acoustic travel time tomography were analysed for two sound directions (9° and 189° seen from the sound source) over a distance of 210 meters. Due to the fact that the wind turns with time the effects of cross-wind directions on the sound propagation can be shown in Figure 3.

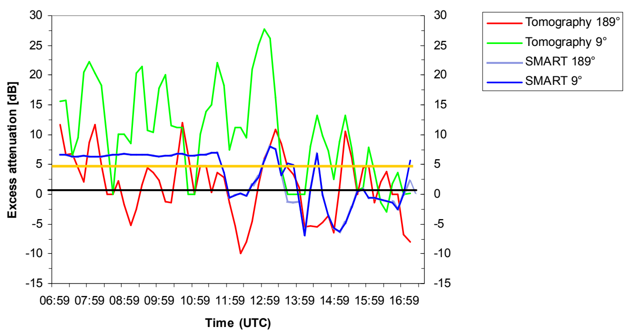

Figure 3: Excess attenuations due to atmosphere and ground during measuring period for a distance of 210 meters. 189° and 9° mean the sound direction (seen from source to receiver), orange line: excess attenuation calculated with VDI-guideline 2714, positive values: noise reducing, negative values: increasing sound immission

In the case of air temperature inversion (see Figure 2) the results of the measurements and of the sound propagation model SAMRT are showing an increasing sound immission. The values of the excess attenuation calculated with VDI 2714 are always positive. During an air inversion in combination with a downwind sound propagation the VDI-guideline predicts smaller sound immission as the measurements are showing. Similar situations results in the case of cross-wind. Through turning wind direction with height are noise intensifications possible.

Figure 4 shows the excess attenuation for the case of up- and downwind sound propagation.

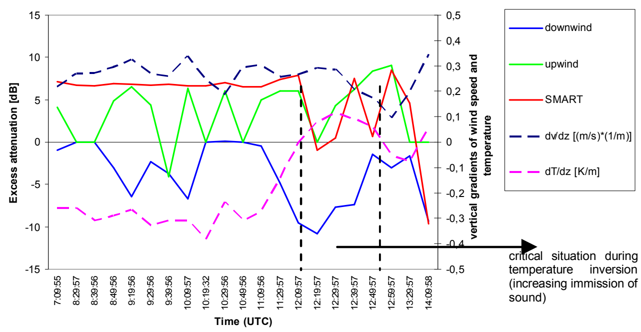

Figure 4: Excess attenuations (up- and downwind) due to atmosphere and ground in comparison to wind and temperature gradient; postitive values: noise reducing, negative values: increasing sound immission

The results of the measurements show a good correlation to the wind direction and to the vertical gradient of air temperature.

Summary

The excess attenuation calculated with a sound-ray model was compared to the results of measurements and VDI-guideline 2714. During an air temperature inversion coupled with a sound propagation in downwind direction the VDI-guideline predicts too small sound immission.

Existing differences between the measurements and the modelled data can lead back to the missing influence of turbulence in sound propagation modelling with SMART. The fact that the measurements of the vertical profiles of wind and temperature are point measurement leads also to differences between the results because the effects of horizontally inhomogeneous temperature and wind distributions can not take into consideration.

References

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