Meteorological influences on the noise reduction potential of forests

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Introduction

The influence of forests on sound propagation is currently under consideration for reducing noise, which is one of the most important environmental problems. Previous studies provide contradictory statements to the noise reduction potential of forests, in particular for the temporally and spatially variable meteorological influence. Thus, a validated model chain of atmospheric and acoustic models was developed and adapted to several environmental and vegetation-specific conditions.

Meteorological-acoustic model chain

To study the influence of forests on the atmospheric boundary layer we used the model HIRVAC (HIgh Resolution Vegetation Atmosphere Coupler) [1].

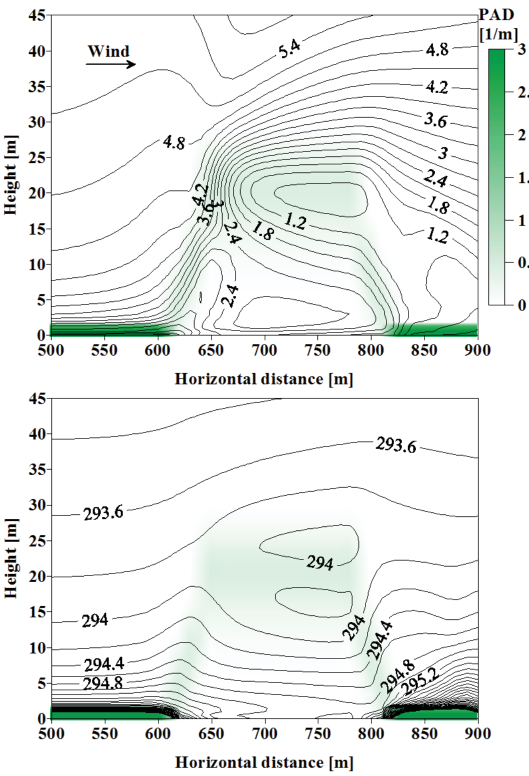

Figure 1: Horizontal wind speed (above, in m/s) and air temperature (below, in K) for a deciduous forest strip (PAD: Plant Area Density) within homogeneous grassland on the 15th July at noon.

A special characteristic of the model is the highly resolved vegetation canopy and the incorporation of vegetation-specific source and sink terms for heat, moisture and momentum [2]. The two-dimensional version of HIRVAC takes the effects of horizontal inhomogeneities of the vegetation characteristics into account. Therewith it is possible to simulate the temporal variations of temperature and wind fields for forests with clearings or forest strips within grassland. Figure 1 displays an example of HIRVAC simulations for a clear summer day. The green colors show the plant area density for a 200 m wide forest area. Please note that the PAD profile depends on the special kind of vegetation.

The vertical profiles of temperature and wind velocity differ between forest and grassland. The wind speed inside the canopy is smaller than outside. A typical secondary wind maximum develops in the trunk space. Furthermore, a temperature inversion occurs inside the canopy opposite to the strong temperature decrease over the grassland.

The different temperature and wind fields inside forest and over grassland result in different effective sound speed profiles. Over grassland, the magnitude of the vertical gradient continuously decreases with height. In contrast, a secondary maximum of the gradient occurs in the crown space. Below this height (depending on the PAD profile), the gradient changes its sign, which results in an acoustic channel. The effect of this channel on the sound level depends especially on the heights of the sound source and receiver. In the downwind direction, behind the forest strip, the effective sound speed gradient converges to the gradient for grassland, but one can still detect the influence of forest. These profiles were used as input data for an acoustic model to simulate the meteorological effect on sound attenuation.

With the Parabolic Equation (PE) method, acoustic wave propagation can be simulated in a horizontally inhomogeneous atmosphere. A Crank-Nicholson PE solution scheme after West et al. [3] was used here. The flow resistance in the ground model is constant for all scenarios (grassland: 200 kPa s/m²). An inhomogeneous ground was considered even for the comparison with measurements (grassland; forest: 50 kPa s/m²). Vertical profiles of sound speed and wind are used to calculate an effective wave number in the CNPE-model [4]. The meteorological influence on the sound level is therefore frequency-dependent. The sound propagation geometry, e.g., heights of sound source (1.4 m) and receiver (1.6 m), was adapted to measurements. To obtain information on sound immissions which are relatively independent of the characteristics of the sound source, sound attenuation values were determined between a fixed reference (26 m distant from source) and another receiver.

Simulated sound attenuation

Sound attenuation from the CNPE-model includes the constant ground effect and the variable meteorological influence. They show a daily and seasonal variability from 1-2 dB for short distance and up to 20 dB for longer distance for a sound frequency of 500 Hz (Figure 2). Attenuation is higher for upwind propagation in most cases. Please note higher attenuation values in downwind compared to upwind direction result for lower frequencies (up to 250 Hz) in a deciduous forest belt.

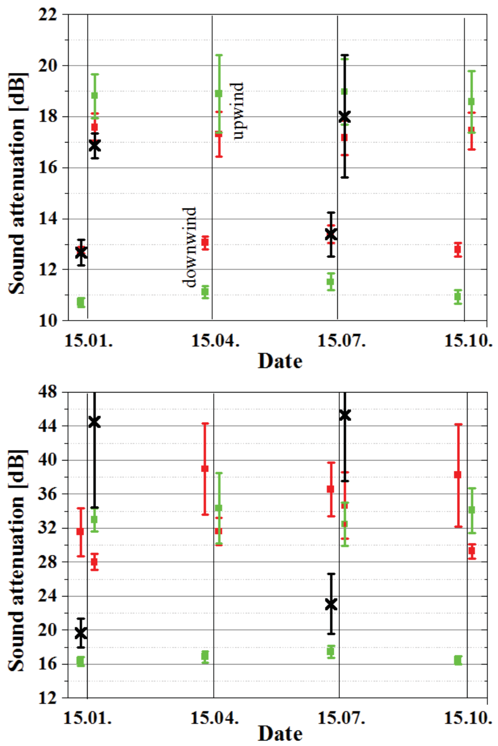

Figure 2: Daily average and standard deviation of sound attenuation at a distance of 48 m (above) and 164 m (below) for a deciduous forest strip (red), coniferous forest strip (green) and grassland (black) for 4 different days. Propagation of a sound wave (500 Hz) in the wind direction (downwind, left of the vertical line for each day) and against it (upwind, right of the vertical line).

In general, downwind propagation is more problematic regarding protection against traffic noise. The comparison between forest and grassland attenuation recommends in this case a deciduous forest strip which results in an additional meteorological attenuation up to 14 dB in summer. Then, differences between sound attenuation in a grassland landscape and in a forest area may be in the range of the total attenuation for road traffic noise.

Comparison of model and measurement results

Intensive measurement campaigns were performed in Tharandt forest (clearing and spruce stand) near Dresden [5]. With the entire model chain (HIRVAC-CNPE), individual days of the measurement campaigns were simulated. Even for low frequencies, the meteorological effect on sound attenuation can be detected. As an example, Figure 3 shows a comparison between simulated and measured sound attenuation data. In the morning and evening hours, during downwind conditions, sound measurements match simulations within the measurement accuracy. Effective sound speed gradients decrease during morning hours followed by an increase in sound attenuation. During the afternoon and evening, gradients increase (sound attenuation decrease) within the vertical layer which is most significant for sound propagation. This diurnal variation is typical for the clearing during an autochthonous weather situation, but it also occurs in the spruce stand.

Attenuation at the larger distance also shows that the measured output is adequately reproduced by the model chain. However, attenuation is slightly greater than the simulated values during the downwind situation, which is likely due to ground and vegetation influences.

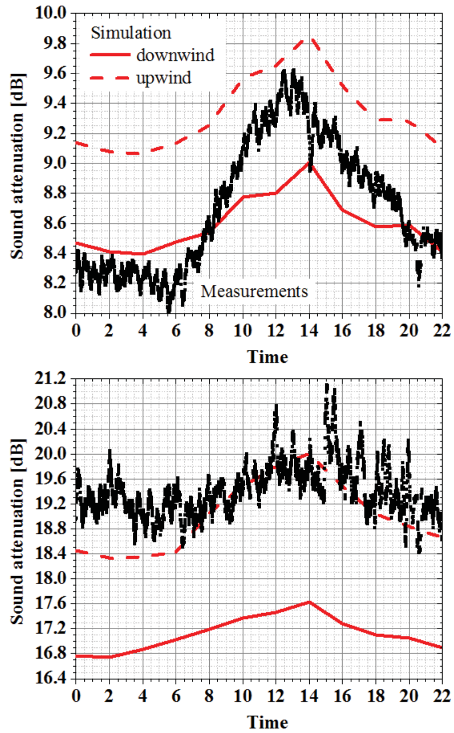

Figure 3: Simulated (red) and measured (black) sound attenuation of an artificial signal (63 Hz) on the 3rd September 2011 at a clearing (above, 48 m distance) and within an old spruce forest (below, 164 m distance).

References

[1] Goldberg, V. and Bernhofer, C.: Quantifying the coupling degree between land surface and the atmospheric boundary layer with the coupled vegetation-atmosphere model HIRVAC. Annales Geophysicae 19 (2001), 581-587

[2] Ziemann, A.: Numerical simulation of meteorological quantities in and above forest canopies. Meteorol. Z. 7 (1998), 120-128

[3] West, M., Gilbert, K., Sack, R. A.: A tutorial on the parabolic equation (PE) model used for long range sound propagation in the atmosphere. Appl. Acoustics 37 (1992), 31-49

[4] Wilson, D. K., Noble, J. M., Coleman, M. A.: Sound propagation in the nocturnal boundary layer. J. Atmos. Sci. 60 (2003), 2473-2486

[5] Ziemann, A., Barth, M., Hehn, M.: Experimental investigation of the meteorologically influenced sound propagation through an inhomogeneous forest site. Meteorol. Z. 22 (2013), 221-229