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Abstract

Sound propagation in the atmospheric boundary layer can be strongly effected by vertical gradients in the wind speed and air temperature, and by atmospheric turbulence. In addition, undulating terrain will either partly shield or focus sound waves, highly impacting sound exposure levels. These aspects become especially important in case of wind turbines present on a ridge, such placement often being efficient to harvest wind energy.

In this work, sound propagation from a large horizontal axis wind turbine towards the adjacent valley is numerically simulated with a hybrid model based on the Green's Function Parabolic Equation method (GFPE). The latter is an efficient and accurate frequency-domain technique, however, with the limitation of one-way sound propagation. The method allows including refraction effects using the effective sound speed approach (arbitrary wind speed and temperature profiles), and accounts for range-dependent ground impedances.

Various approaches for introducing undulating terrain applicable to the Parabolic Equation method exist like the general terrain PE [1], the rotated reference frame approach [2], a stair-step terrain using Kirchoff's method, and the conformal mapping method [3]. These techniques all have significant limitations regarding maximum (local) slope angle, the specific shape of the terrain, the neglect of focusing sound in concave geometries, limitations regarding the ratio between propagation distance and the maximum local terrain slope, or being not directly applicable to the (very efficient) Green's Function PE.

In this study, the conformal mapping method is used, which is a computationally efficient approach to account for undulating terrain. The main limitation here is the need for simplification to circularly curved terrain segments. The geometry of interest is therefore idealized to sound propagation over a small convex circle segment, representing the ridge, followed by sound propagation over part of a large concave circle representing the valley (see Fig. 1). Circular segments could be placed in series following the conformal mapping method [4].

However, given the large sound source height, specific for wind turbine sound propagation problems, some issues arise. The conformal mapping method is not directly applicable for cases where the source height is not small relative to the local radius of curvature of the ground [4]. In addition, one has to account for a fundamental approximation leading to the Parabolic Equation method : sound propagation is only accurately described in a cone, horizontally centered around the source. In the current context, neglecting the latter would lead to artificially putting a major part of the valley in an acoustic shadow zone.

To overcome these problems, a method has been developed by explicitly calculating a starting field at the interface (see Fig. 1) between the ridge and valley, by using an exact analytical solution for sound diffraction around an impedance cylinder [5].

Simulations with this method show the strong asymmetry in exposure along the valley (see Fig. 2), with a significant lower level at the source side of the valley relative to free field sound propagation. At the opposite side of the valley, near-free field sound propagation is predicted in case of rigid ground. The method could help choosing optimal placement of wind turbines at ridges in function of the zones where receivers are expected along the valley.

References

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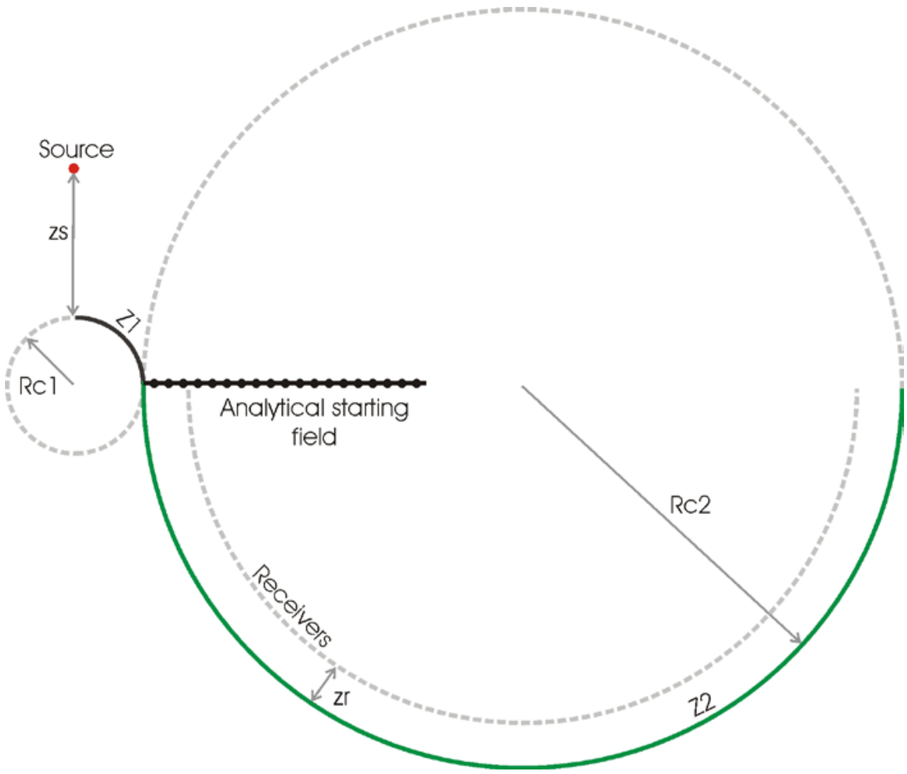

Figure 1. Geometry considered for simulating sound propagation from an elevated sound source positioned at a ridge (wind turbine approached by a point source at hub height *zs*) towards an adjacent valley where the sound exposure needs to be assessed (at fixed receiver heights *zr*). An analytical approach for sound scattering by an impedance (*Z1*) cylinder is coupled to the conformal mapping Green's Function Parabolic Equation method (over an impedance ground *Z2*).

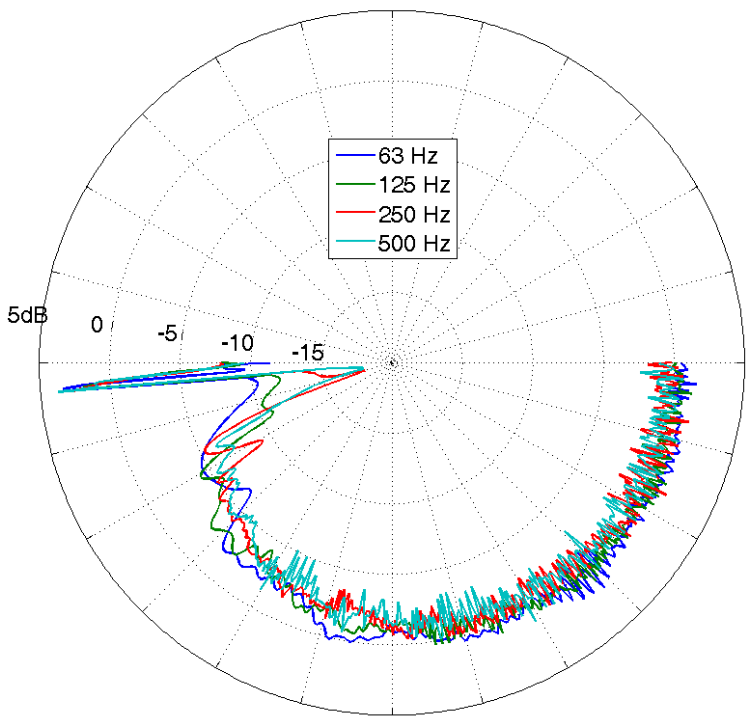

Figure 2. Sound pressure level, relative to free field sound propagation (in dB) along the valley at a few octave bands. The decrease in level due to the distance effect (geometrical spreading) is excluded when expressing levels relative to free field propagation.

Positive values mean amplification due to the combination of terrain (shielding or focusing), soil reflection. Wind refraction is not included in the results presented here.

Following parameters were used : zs= 50m, zr= 4m, Rc1= 10m, Rc2= 500m, Z1=Z2=∞ , meaning rigid soil for both the ridge and valley.