OUTDOORS SOUND PROPAGATION IN COMPLEX ENVIRONMENTS: RECENT DEVELOPMENTS IN THE PE METHOD.

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ABSTRACT

During the last decade significant progress has been made in the modelling of sound propagation over distances ranging from hundreds meters to kilometres, and the agreement between calculated and measured fields has been greatly improved. New developments appear in the parabolic-equation method. In this paper we present a method which evaluates the propagation of an acoustic wave above non-flat terrain including realistic meteorological parameters. In our approach the effects of the topography are modelled using appropriate rotated co-ordinates systems in order to treat the non-flat ground as a succession of flat domains. Our model of outdoors sound propagation is validated both with classical numerical benchmark cases and recent outdoor experiments done in St-Berthevin.

INTRODUCTION

During the last decade, the propagation of sound above plane and heterogeneous grounds has been extensively studied analytically, numerically and/or experimentally. However in complex environments, the modelling of outdoor noise pollution implies to take into account the mixed influence of the terrain topography and the atmospheric conditions. Sound waves are influenced by two principal characteristics: the sound speed (celerity) of the medium, and the velocity of the medium. Variations in sound speed across the medium, for example, can create focusing and defocusing and affect the entire sound field. If the medium is not stationary, i.e., it exhibits mean motion or velocity fluctuations, sound waves are convected by the mean motion of the field and scattered by velocity gradients. For numerical simulations of outdoors sound propagation, parabolic equations have been derived using the approximation of the effective sound speed. In this conventional approach the real moving atmosphere is replaced by a hypothetical motionless medium with the effective sound speed $c_{eff} = c + v_x$ where v_x is the wind velocity component along the direction of propagation between source and receiver. When the source and receiver are close to the ground, the preferred direction of sound propagation is nearly horizontal, and standard parabolic equations can be used to predict sound pressure levels. However, in many problems of atmospheric acoustics, refracted sound waves and those scattered by turbulence propagate in directions which may significantly differ from the horizontal

axis. A rigorous way to incorporate the effects of a velocity field is to begin with the fundamental equations of fluid mechanics and derive a wave equation which includes the velocity. In the limits of linear acoustic theory, such a wave equation can be derived as the sum of a d'Alembertian operator and additional terms depending on the nature of the velocity field. From such a wave equation, a corresponding ``vector" parabolic equation can be derived for monochromatic sound waves. Recently Ostashev & al.([1]), Dallois & al. ([2]), derived new wide-angle parabolic equations which do maintain the vector properties of the velocity of the medium.
Significant progresses have been made in the modelling of sound propagation over distances ranging from hundreds meters to kilometers, and the agreement between calculated and measured fields have been greatly improved ([3], [4]).

In this paper we present a method which evaluates the propagation of an acoustic wave above non-flat terrain using a PE method and which includes realistic meteorological parameters. In our approach the effects of the topography are modelled using appropriate rotated co-ordinates systems in order to treat the non-flat ground as a succession of flat domains. Our model of outdoors sound propagation is validated both with classical numerical benchmark cases and recent experiments done in St-Berthevin. Acoustical and meteorological measurements are performed simultaneously.

PARABOLIC EQUATION.

Several acoustic researchers have recently studied the problem of the propagation above a non-flat ground. A curved terrain version of the parabolic equation has been adapted for acoustic propagation in the atmosphere over fairly simple terrain profiles which can be reduced to a set of joined circular section pieces ([5]). In that approach, a separate conformal coordinate transformation was applied to each circular section piece of atmosphere. Sack and West ([6]) chose to use a transformation which follows the terrain profile. Their method can be used for any smooth terrain but seems difficult to apply for a parabolic equation including wind terms. We chose to develop another model which can be used above any terrain and with a parabolic equation including wind terms. The non-flat ground is treated as a succession of flat domains (see figure 1).

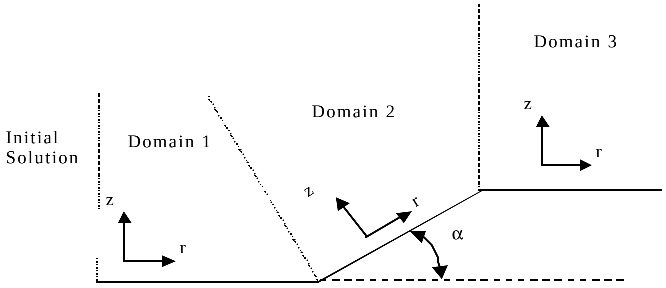

Figure 1 *Geometry of the problem*

After each flat domain the coordinate system (r,z) is rotated so that the r axis stays parallel to the ground. The calculation above each domain needs an initial solution. The values of the initial solution for the domain n+1 are obtained from the values of the pressure field of the domain n, except for the first domain where a gaussian starter is used. The propagation code is based on the parabolic equation and a Split-Step Padé method. Introducing a thin artificial absorption layer in the upper part of the domain controls reflexions at the top of the computation domain. The code has been tested in realistic outdoor configurations. The case of an impedance discontinuity (infinite/finite) in a stratified atmosphere has been validated (more details are given in [7]).

PROPAGATION OVER A NON FLAT TERRAIN

An outdoor site near Saint Berthevin (France) has been selected to study the influence of meteorological conditions on noise traffic. This offers the possibility of simultaneous detailed measurement of meteorological and noise propagation data as indicated on figure 2

Figure 2 *View of St Berthevin*

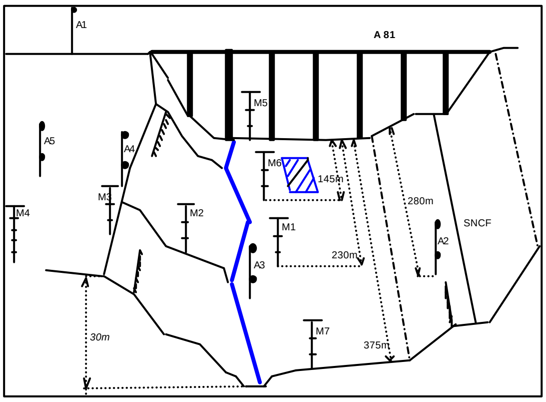

Figure 3 *Schematic illustration of the experimental set –up.*

The meteorological data are collected on towers M1 to M7 at z= 3,10 and 24 m., and the sound pressure levels are measured on towers A1 to A5. Meteorological data and sound levels at the receivers are recorded simultaneously. (Additional details are available in [8]). This survey provide a database of noise level variations in a complex environment (non flat terrain, mixed ground) and thus allow us to validate our numerical simulation of outdoors sound propagation. In the case of an homogeneous atmosphere, we calculated the sound pressure level using the PE method. The terrain is modelled using a succession of six flat domains with finite complex impedance Z. Z is calculated using the one-parameter formula of Delany-Bazley

$$\frac{Z}{Z_0} = 1 + 9.08 \times \left(\frac{f}{s}\right)^{-0.754} + i \times 11.9 \times \left(\frac{f}{s}\right)^{-0.732}$$

where f is the frequency and σ is the flow resistivity (Z is expressed in mks units). The source is located at 2m from the ground, the reference level is calculated in front of the source at a distance of 1m. The relative sound pressure levels using the PE are plotted on figure 4 for different frequencies of the source (250 Hz, 500 Hz, 1000 Hz, 2000 Hz). The ground is cover with grass ($s = 200\ kNms^{-4}$). On this figure we clearly observed the diffraction phenomena due to the wedges introduced by the variation of the slope along the direction of propagation. For high frequencies we also noted the occurrence of an acoustic shadow zone down the hill.

Figure 6 gives a comparison between experimental data measured at St Berthevin and numerical simulations calculated with PE. A broadband source was placed 2m above the ground and the receivers were located 2m above the ground (see figure 5). In the results presented here, the direction of the mean wind was 20° North and the mean vertical velocity profile $u(z)$ was modelled using a logarithmic law $u(z) = a\ln(1 + z/z_0)$ with $a = 1.2$ and $z_0 = 0.1\,m$. The flow resistivity of the ground has been measured using a method developped by Bérengier et al.([9]). From the source to the receiver R1 we obtained $s = 600\ kNms^{-4}$, and from R1 to R5 we had $s = 90\ kNms^{-4}$. The distances of propagation are respectively 25 m for the receiver R2 and 75 m for the receiver R5. At the receiver R5 placed down the hill we clearly observed the influence of the wind (see figure 6). If the mean wind profile is not taken into account in the numerical simulation we noted large differences between the measured data and the estimated sound pressure level ; at large distance of propagation (R5) and for high

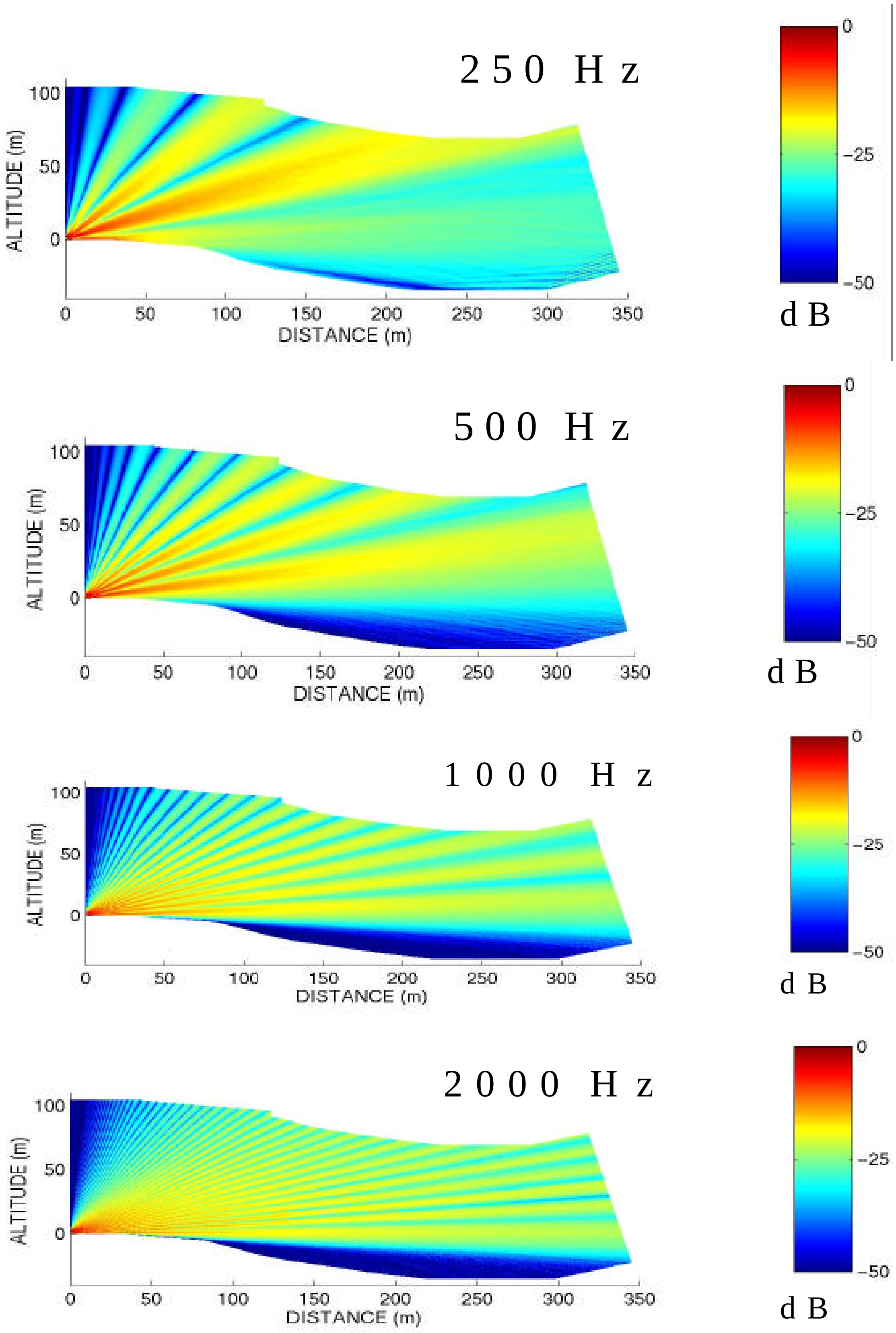

Figure 4 *Relative sound pressure levels calculated with the PE method in the case of an homogeneous atmosphere. The source is placed 2m above the ground.*

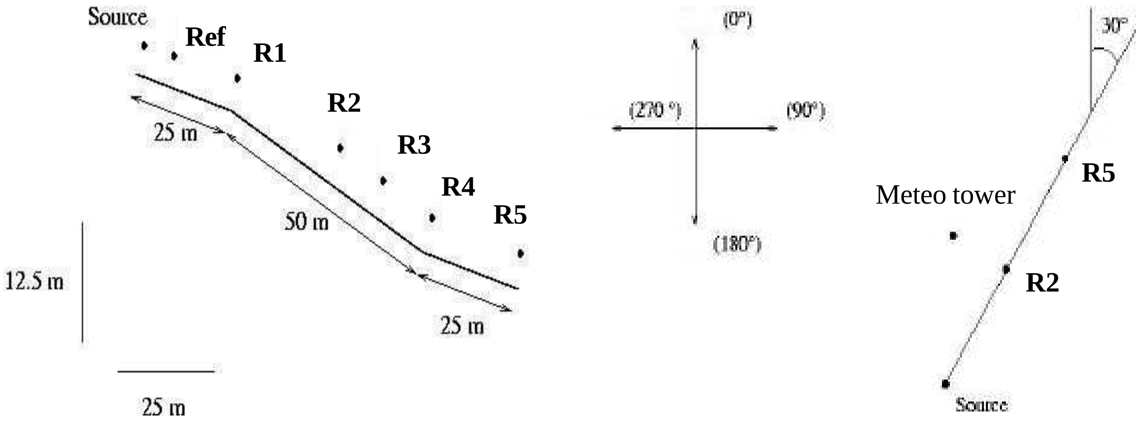

Figure 5 *Experimental set-up .The source and the receivers R1 – R5 are located 2 m above the ground, the angle between the wind direction and the axis of propagation is 30° .*

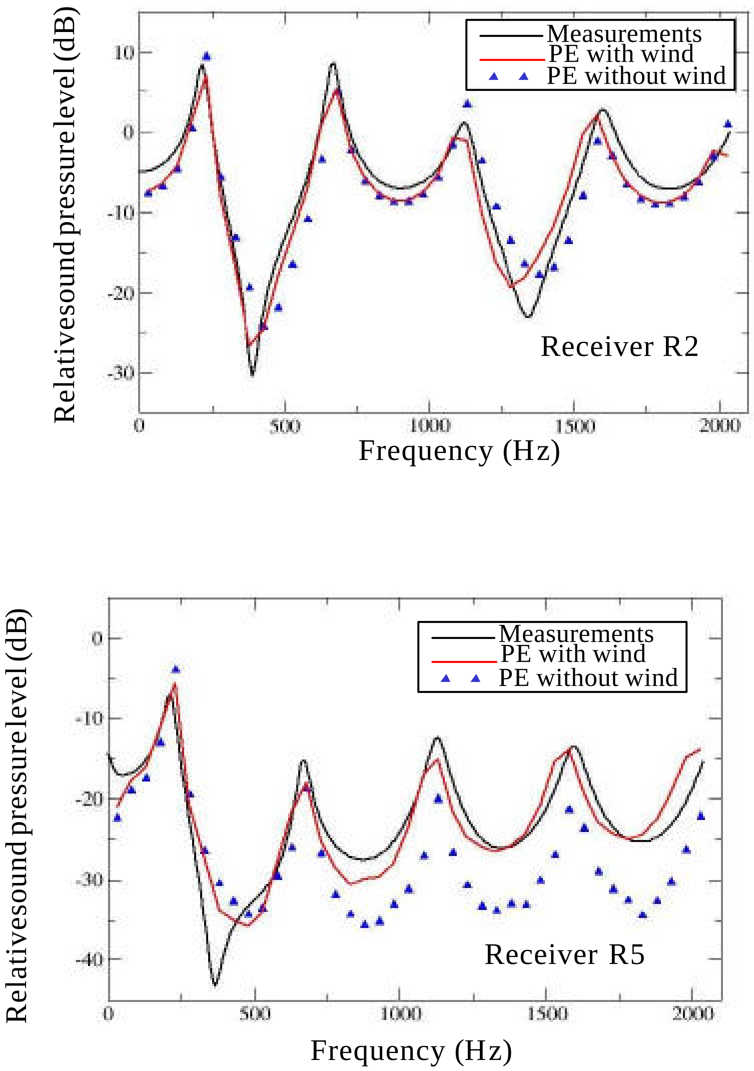

Figure 6 *Relative sound pressure levels measured at two receivers R2 and R5. Comparisons with numerical estimated calculated using the PE method: influence of the mean wind.*

frequencies (above 500 Hz) the difference is of the order of 15dB. When the mean velocity profile is taken into account in the PE simulation, the agreement between calculated and measured values is reasonable. The differences could be attributed to the variations of the local impedance, and to the fluctuations of the meteorological parameters (mainly the wind direction and the turbulence).

CONCLUSION

In this paper we have presented a numerical model to simulate the propagation of acoustic waves in the atmosphere near a non flat ground, with the combined effect of mean sound speed gradients and complex terrain. In our technique the ground is represented as a succession of flat surfaces with an appropriate impedance. An outdoor site near Saint-Berthevin (France) has been selected to study the influence of meteorological conditions on noise traffic. Acoustical and meteorological measurements are performed simultaneously. This survey provides a database of noise level variations in a complex environment (non-flat terrain, mixed ground). The agreement we obtained between our numerical simulation based on a PE model and the measured data can be considered as very promising. Work is currently in progress to study over long time periods the statistical effects of meteorology on long range sound propagation.

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