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SOUND PROPAGATION IN A VALLEY-SLOPE CONFIGURATION: MEASUREMENTS AND SIMULATIONS

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ABSTRACT
In this study, detailed sound propagation calculations are compared to noise measurements accompanied by meteorological observations, in a valley-slope configuration in the Alps (Unterinntal region, Austria). The sound source considered is road traffic along the centre axis of a valley. Noise levels were measured in different cross-sections, with receivers in the valley and upslope. For the numerical calculations, the rotated Green's Function Parabolic Equation method is used, taking into account the undulation of the terrain and an inhomogeneous atmosphere. Two measurement campaigns were set-up, one during the winter (snow-covered ground), and one during spring-summer (grass-covered ground). Predictions agree with measurements to within 3 dBA, for propagation distances up to 1 km, in windless conditions. This study shows that accurate sound level prediction in a valley-slope configuration requires detailed numerical calculations. The difference between summer and winter measurements is very limited when the atmospheric conditions are similar.

INTRODUCTION
Sound propagation in a valley-slope configuration is influenced to an important degree by the undulation of the terrain and by the typical meteorological conditions that can be found in mountainous regions. The sloping of the terrain can shield receivers or the sound source. On the other hand, there is often direct visibility on the source high on the slopes. Such receivers are exposed to significantly higher sound pressure levels than receivers at the same distance at the level of the valley floor. Furthermore, multiple reflected sound waves may converge for upslope receivers in concave valleys, and sound can be reflected on opposite, steep slopes [1].

Meteorological conditions have a large variability in space and time in mountainous areas. Wind can be channelled along the valley axis, and large recirculation zones may be observed near mountains. Thermally driven air currents, that are called slope winds, are typically observed in valley-slope configurations. Furthermore, temperature effects can be more prominent in valleys compared to flat terrain. The transition from the nightly temperature inversion situation to an unstable atmosphere during day-time can happen very quickly, once the sun rays reach the valley floor. The valley orientation plays an important role in this respect and might cause a delay of several hours with regard to the moment of temperature inversion break-up [2].

In Ref. [3], a numerical meteorological model was coupled to a (particle) sound propagation model in a valley-slope configuration. This study showed large variations of sound levels during the course of a day because of the state of the atmosphere.

In this study, simultaneous noise and meteorological measurements were performed in order to check detailed wave-based sound propagation calculations. Measurements were performed during winter time (with snow-covered ground) and summer time. The situation of interest is upslope sound propagation, orthogonal to the valley axis. This corresponds to a typical situation in valley-slope configurations, where a highway or railway follows the valley axis and where dwellings are present on the slopes.

In this paper, focus is on the effect of an inhomogeneous atmosphere. Only windless periods were retained from the measurements.

METEOROLOGICAL AND NOISE MEASUREMENTS

The measurements were performed in the Unterinntal region, in the Alps, in the western part of Austria. The study region is a 2 km-wide valley. The valley floor is located at an elevation between 530 m and 540 m. The mountains surrounding the valley have ridges of over 2000 m height. Noise from an important highway, in the centre of the valley, is considered. Different cross sections were selected, and in each of them simultaneous noise measurements were performed at 3 locations. The microphone positions in each cross section lie more or less on a straight line, orthogonal to the roads. On-site meteorological data is recorded. Air temperature, relative humidity, atmospheric pressure, wind speed, and wind direction are measured at 2 m above the ground, and logged every minute.

Temperature profiles were obtained by means of ventilated temperature sensors attached to the posts of a nearby cable way. The heights of the sensors ranged from the valley floor to 1341 m. Every 15 minutes, the temperature at all heights was logged simultaneously. This means that air temperature is known along a single line on a slope. Horizontal temperature stratification throughout the valley is further assumed.

Overall equivalent A-weighted sound pressure levels are stored every second. After excluding events, 1-minute equivalent sound pressure levels are used for comparison with numerical calculations.

The measurement campaign led to a dataset of combined noise and meteorological data. A clustering of these data was done based on (similar) temperature profiles, in order to limit the number of calculations. The minimum number of data points in each cluster was set to 50 to allow one to draw statistically stable conclusions.

Information on traffic is lacking. Therefore, the location closest to the road in each cross section was chosen as a reference measurement. This relative approach will be used for validating the sound propagation model. The traffic intensity is assumed to be homogeneous over a sufficiently long stretch of the road near the receivers. A different traffic composition on the road however influences the magnitude of the relative measurements: Each combination of vehicle type and vehicle speed results in a typical source spectrum. To account for this, the spread in sound pressure level caused by different vehicle types, driving at typical velocities, will be predicted.

NUMERICAL CALCULATIONS

A two-dimensional Green's Function Parabolic Equation (GFPE), method with a rotated reference frame (abbreviated as GFrPE) is used for the numerical predictions. In this model, the undulating terrain is approximated by a succession of flat domains with different slopes [4]. In each of them, ordinary GFPE calculations are performed.

The GFrPE model could become computational costly. Therefore, typical parameters related to GFrPE were optimized to increase computational efficiency.

The three-dimensional propagation problem is split up in a set of two-dimensional problems by subdividing the roads in a number of point sources along its axes. This is illustrated in Figure 1. The terrain profile along the line between each point source and the receiver is extracted from the digital terrain map, and approximated as a succession of flat segments with different slopes. Diffraction over buildings, highway screens and railways screens is accounted for by using the Kirchoff approach. Sound attenuation is each two-dimensional cross-section is calculated with GFrPE. In a final step, all the contributions from the relevant point sources are added incoherently to find the total sound pressure level at the receiver. The centre frequencies of the one-third octave bands ranging from 50 Hz to 2500 Hz were considered. The one-parameter Delany and Bazley model [5] is used to model ground reflection. For the snow-covered ground (winter) a flow resistivity of 30 kPas/m2 is used, for grass-covered ground (summer) 200 kPas/m2.

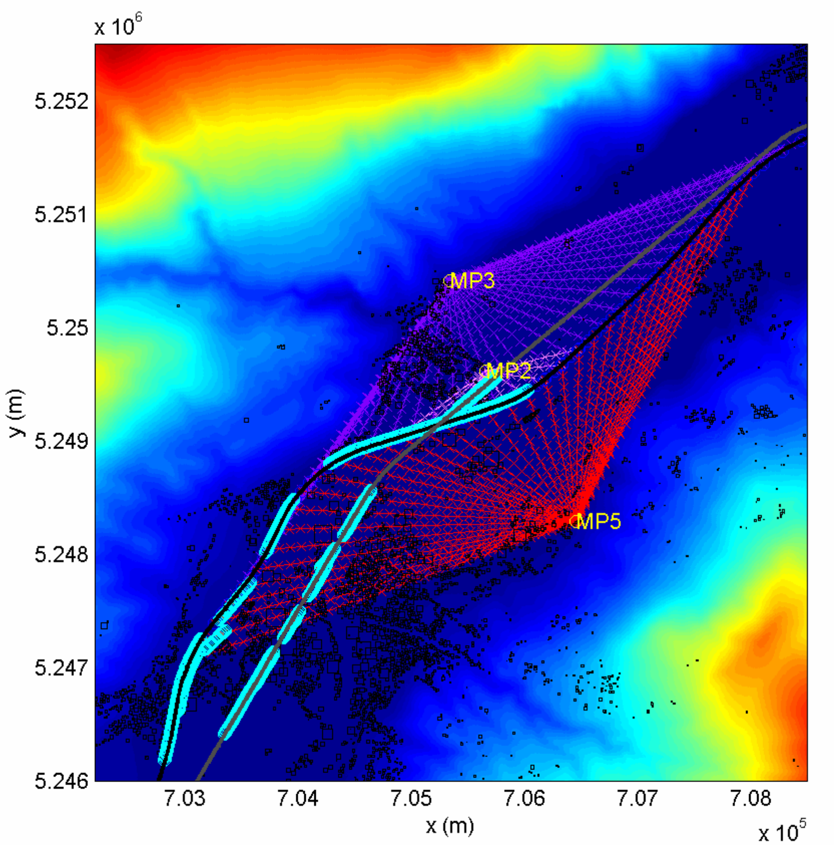

Figure 1.- Sound paths contributing to measuring points 2, 3 and 5, plotted on the digital elevation map. The highway is indicated by the black line, a railway by the gray line. Noise screens are shown in cyan; buildings are indicated with the black rectangles.

RESULTS AND DISCUSSION

Results from a single cross-section, in winter and summer, are shown in Figure 2. A similar temperature profile cluster is selected in both periods. The measurements are presented by means of boxplots. Each data point represents a (relative) one-minute L_{Aeq} measurement. Different sets of predicted relative noise levels are included in the plots. The first set is the best available prediction. To gain understanding in the importance of the terrain elevation and temperature effects, additional calculations were performed. Firstly, a homogeneous atmosphere was assumed in the presence of the actual relief. Secondly, a flat terrain is assumed in a homogeneous atmosphere. In both calculations all other numerical and geometrical parameters remain unchanged.

There is an important spread in the measurements. First, traffic composition and vehicle speed may differ from minute to minute. Another reason is that atmospheric absorption changes over time. Since an average (clustered) air temperature profile is used, part of the variation could come as well from a different refractive state of the atmosphere within each cluster. The first two causes of variance are accounted for in the predictions, the last one is not.

The agreement between measurements and numerical predictions is good. The average of the calculations lies close to the median of the measurements. Differences range up to 2-3 dBA. The spread in the calculations is in most situations very similar to the measured one.

The presence of the sloping terrain is responsible for an important increase in sound pressure level for the distant observation points. This is seen when comparing the flat terrain calculations with the calculations using the actual relief. Comparing the calculations in the case of a homogeneous and an inhomogeneous atmosphere, both using the actual relief, reveals that temperature gradients in this Alpine valley results in either a decrease (see Figure 2) or increase (other cross-sections, not shown) of the relative sound pressure level.

The medians of the measured relative sound pressure levels stay between -5 dBA and 0 dBA. The relief in combination with the refracting atmosphere compensate for the effect of geometric divergence of the sound wave, ground attenuation and atmospheric absorption. The decrease of sound level with distance, as is commonly expected, can not be generalized to a mountainous region. The difference between summer and winter measurements is limited. Since snow is an acoustically softer ground, the differences between MP3 and MP5, compared to MP2, are significantly larger during winter time, in case the elevation of the terrain is not taken into account. However, when accounting for the actual relief, ground attenuation seemed of limited importance.

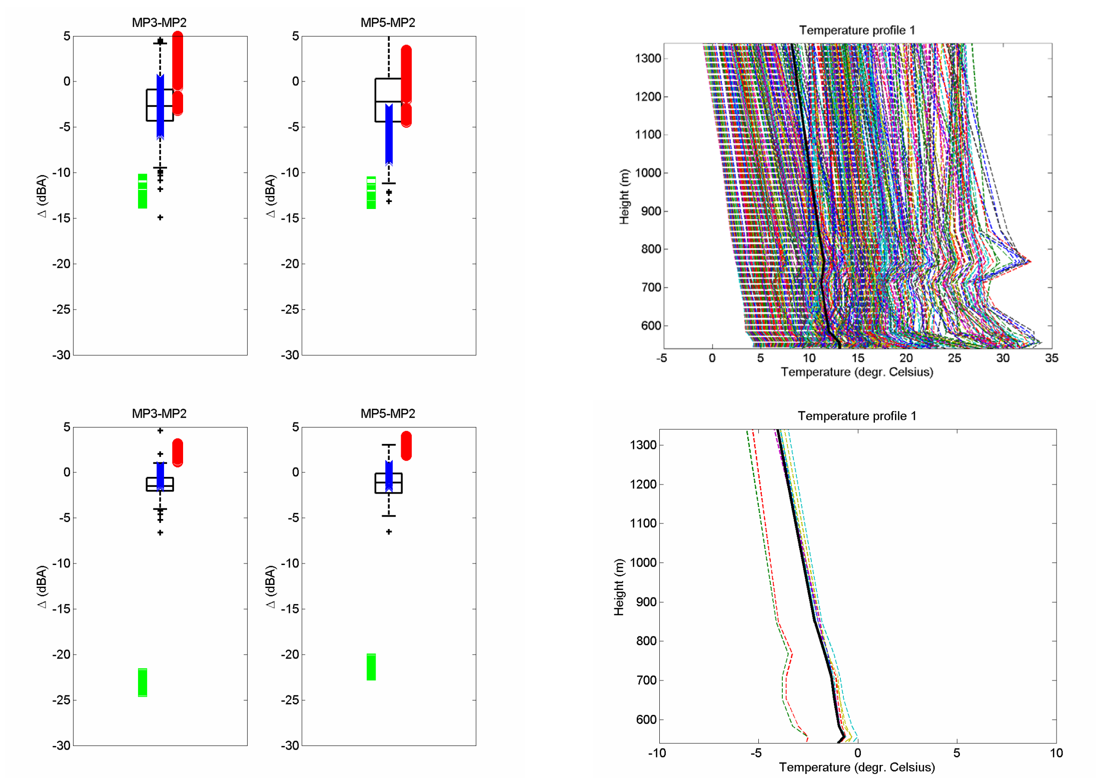

Figure 2.- Measurements (indicated by boxplots) and numerical predictions (indicated by symbols - *blue crosses*: actual terrain + inhomogeneous atmosphere; *red circles*: actual terrain + homogeneous atmosphere; *green squares*: flat terrain + homogeneous atmosphere). On the right, the temperature profile cluster is shown, with the average profile in the full black lines. The summer measurements are shown above, the winter measurements below.

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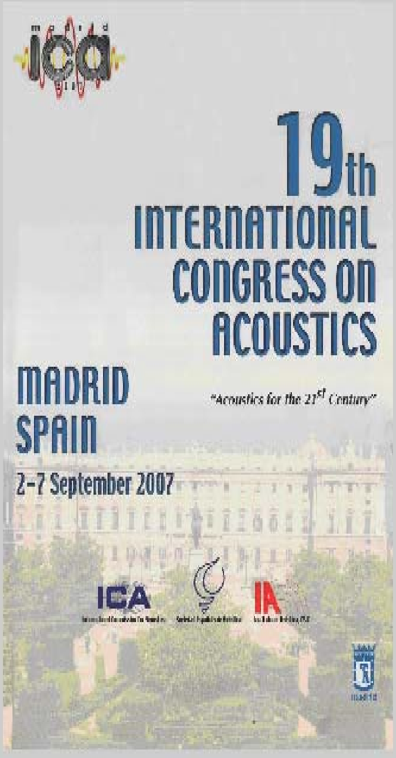

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