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Modelling reflections from single trees and entire forests

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ABSTRACT

A model for the prediction of diffuse reflections from forested areas is presented. A single tree is thereby modelled as a cylinder of finite height, representing the trunk, and a number of spheres to account for reflections from the crown. The scattering properties of the involved structures are derived from the classical analytical solutions, complemented by a Fresnel zone weighting. For performance reasons not every tree in a forest is modelled individually but representative super trees are distributed over forested areas with a finer local resolution along the forest edges and a coarser representation in the depth of the forest. The model is formulated in one-third octave bands and yields sound exposure level as well as maximum sound pressure level. As the depth of the forest is automatically scaled correctly, it can be applied for small-scaled vegetation and is for example capable of predicting levels behind forested barriers or berms. Comparisons with measurements showed a generally good agreement.

Keywords: Sound propagation, Vegetation, Reflections

1. INTRODUCTION

The presence of vegetation influences sound propagation in manifold ways. Already known for a long-time is the additional attenuation produced by belts of trees (1, 2). It is primarily explained by the presence of trunks, branches and leaves, the latter being relevant at higher frequencies, and by the fact that forest soils are typically softer and therefore lead to more prominent ground-effect dips (3, 4). In addition, vegetation has an influence on temperature and wind profiles with typically smaller gradients within forests compared to open fields (5, 6). Consequently, as barrier effects are reduced under down-wind conditions, the presence of trees increases barrier attenuation (7). Apart from this, trees can also act as reflectors and hence lead to an increase of sound exposure (8). Approaches to account for the effect of vegetation range from simple distance and frequency dependent attenuations as presented for example in ISO 9613, part 2 (9) to sophisticated FDTD-models, that even account for microclimatic influences (10, 11).

In this contribution, a forest reflection model is presented that starts from an analytical description of a single tree and extends this approach to entire forests. The model represents a further development of previous work described in (12) and (13). In the previous model, the reflection was assumed to be stemming from the forest edge. In the current model representative trees are spread over the entire forested area. The calculation method has been implemented in the most recent versions of the Swiss engineering models for shooting and aircraft noise, sonARMS and sonAIR (14, 15). Therefore, several simplifications and optimizations have been introduced to allow for a computationally efficient implementation.

2. MODEL DESCRIPTION

2.1 Reflections of a single tree

A single tree is represented by the trunk and the tree crown. The scattering by the trunk is modelled based on an analytical solution for rigid cylinders given in (16). To account for the finite height of the tree a Fresnel-zone approach as described in (13) is applied. The tree crown is modelled as a number of

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scattering spheres, which for simplicity are cumulated at 10 m height at the position of the trunk. An analytical solution for the scattering of rigid spheres as given in (17) is used.

Based on forest statistics from Switzerland an average number of trees of 5 per 100 m^2, an average diameter of 27.5 cm and an average height of 20 m was determined (12). The properties of the crown were derived in comparison with measurements in short distance. On this basis, a sphere diameter of 15 cm and a total of 350 scattering spheres was deduced. The corresponding reflectivity for trunk und crown are stored as a look-up table for specific scattering angles and a frequency range from 25 Hz to 5 kHz.

2.2 Propagation calculation

The propagation calculation accounts for geometrical spreading, air absorption, ground effect, foliage attenuation and reflectivity. Air absorption is calculated according to ISO 9613-1 (18). Diffraction is not explicitly taken into account. Calculations are suppressed if either the line of sight from source to the middle of the trunk or from the trunk to the receiver is blocked. To reduce computing effort a standardized ground-effect spectrum is used (13). For the part of the propagation path that takes place in a forest, foliage attenuation according to ISO 9613-2 (9) is applied.

2.3 Extension to entire forest – discretization strategy

The information on forested areas is taken from land-use data provided in a horizontal grid, with a typical mesh size of 5 m. As a first step, a representative tree is placed in the center of each cell. However, taking into account that potentially large areas are covered with trees and that propagation calculations are performed for each combination of source, reflecting tree and receiver, this is likely to result in a very high number of propagation calculations and impracticable long calculation times. Therefore superior mesh structures are introduced. In case that all four unit cells within a superior cell are of the type forest, they are aggregated and a super tree is introduced in the center of the superior cell with a four times higher reflection strength. This merging step is executed four times, resulting in a maximum grid size of 80 m. Figure 1 shows on the left an example of this discretization strategy, resulting in bigger structures in the middle of the forest while the forest rim is represented by substantially finer structures. This feature is highly intended as simulations indicate that the first rows of trees at the forest rim are responsible for the majority of the reflections in front of the forest (12).

However, the number of remaining super trees is still comparably large. Nevertheless, repeating the described aggregation step even further or starting with a coarser basic grid would not have been expedient. As the majority of the remaining reflectors is located at the forest rim the first approach would not result in a substantial reduction of the number of reflectors. The second approach would shift the position of the super trees deeper into the forest, further away from the forest rim, consequently leading to an underestimation of the resulting reflections close to the forest edge.

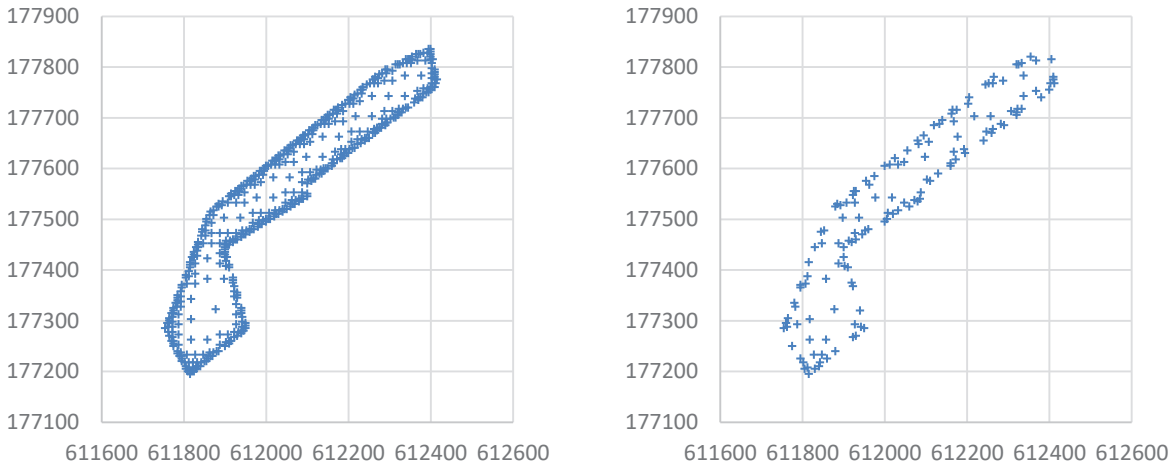

Figure 1 – Examples of the discretization strategy showing the remaining super trees for a forest of 0.9 km^2. Grid size is in both cases 5 m. The graph to the left shows the situation after merging to superior structures, resulting in 504 super trees. The graph to the right shows the same situation after applying an additional reduction by a factor of 5.

Therefore, an alternative concept was introduced in which the position of the super trees is left unaltered, but only a reduced number of reflectors is considered in the propagation calculation and the weight of the omitted super trees is summed up accordingly. The reduction strategy is thereby formulated such that the reduction only takes place within elements of identical cell size. In addition, it follows a pattern that avoids geometrical distortions, i.e., a drift of the reflector positions in a specific direction (see Figure 1 on the right).

2.4 Reproduction of temporal pattern and calculation of maximum sound pressure levels

The shooting noise model sonARMS (14) yields as output not only sound exposure level but also maximum sound pressure level. Consequently the calculation scheme of the sound propagation core is designed to store for each propagation path not only the corresponding attenuation but also the runtime of the sound wave.

Forest reflections cause sustained echoes, composed of the contributions of numerous trees and branches. By introducing the concept of super trees, the temporal pattern of these reflections will become uneasy and maximum levels are likely to be overestimated. Therefore, as already proposed in (14), an additional temporal smoothing step with a time constant of 150 ms is introduced. This setting turned out to yield plausible results for a wide range of reflector discretizations.

3. Verification

In (13), forest reflection measurements at four sites, consisting of 66 source-receiver-combinations, were presented and compared with calculations. Two sites were on a plane and two sites on a valley slope, with source and receiver at a lower level than the forest rim. Sound sources were either explosions or pistol shots. In all cases, sources and receivers were on the same side of the forest edge. These measurements were again used for comparison with the recent forest reflection model. As this dataset had also been used to derive the reflection properties of the crown (see section 2.1) the comparison cannot be used as a validation but serves only as a model verification. The calculations were performed with a 5 m basic grid, 4 aggregation rounds and a reduction factor of 5, as depicted in Figure 1.

Figure 2 shows measured vs. calculated A-weighted attenuations. The attenuation is thereby defined as the difference of the sound power spectrum of the source and the measured or calculated sound exposure spectrum. Situations with attenuations between 40 and 60 dB(A) featured source as well as receiver distances from the forest rim below 50 m. In contrast the situations with higher attenuations exhibited substantially greater distances with sources that were up to 500 m and receiver that were up to 300 m away from the forest rim.

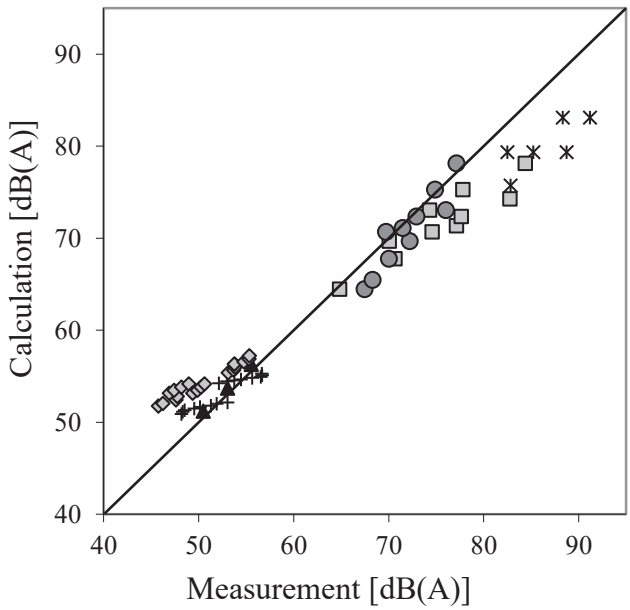

Figure 2 – Comparison of measured vs. calculated A-weighted attenuations.

Deviations from the one-to-one line are primarily visible in two parts. At low attenuations, i.e., short propagation distances, the deviations are assumed a consequence of the different tree types. At these comparably short distances, the A-weighted levels are dominated by the contribution from the tree crown. In case of the measurement data depicted with diamonds, the forest was dominated by hardwood trees with large, low-hanging branches. In contrast the other site with identical geometries exhibited only softwood with small branches. Hence it can be concluded that the indicated range of uncertainty cannot be avoided with a uniform parameter setting.

At greater propagation distances, a tendency to underestimate attenuations and hence to overestimate the resulting sound exposure level, becomes obvious. This finding is explained by meteorological influences on sound propagation. The measurements showing the greatest deviations, depicted with stars, were performed on a calm, sunny summer day. Consequently it can be assumed that up-wind conditions were present on the propagation from the source to the forest as well as on the path from the forest to the receiver. The upper two graphs in Figure 3, showing measured vs. calculated spectra, clearly demonstrate the meteorological influence on sound propagation. The lower two show the already mentioned influence of the type of forest.

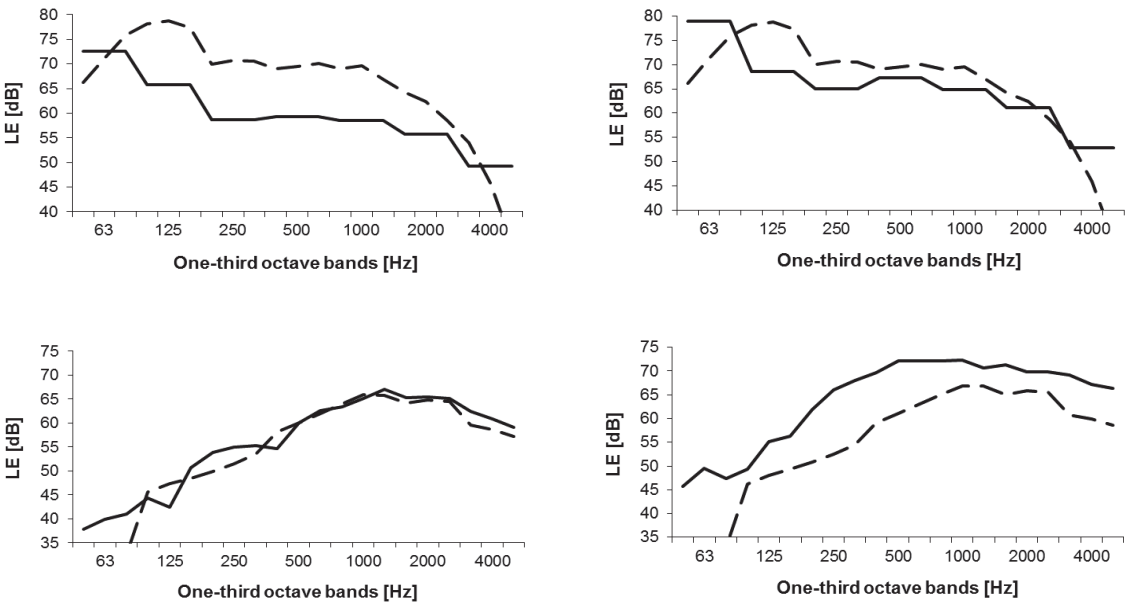

Figure 3 – Examples of measured (bold line) vs. calculated (dashed line) sound exposure level. Upper two examples: explosions of 200 gr TNT, propagation distance 680 m, unfavorable (left) and favorable (right) sound propagation conditions. Lower two examples: signal pistol, propagation distance 50 m, softwood forest (left) and hardwood forest with low-hanging thick branches (right).

Figure 4 shows in addition a measured vs. calculated level vs. time pattern of the reflection of an explosion 50 m in front of the forest rim, measured in 100 m distance from the forest.

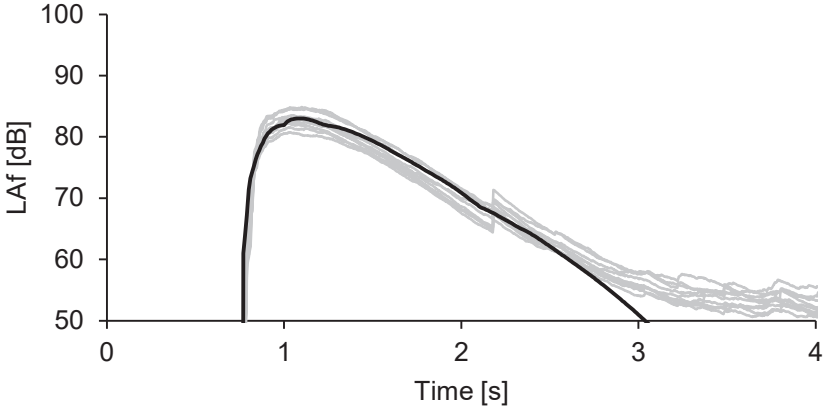

Figure 4 – Examples of measured (grey lines) vs. calculated (black line) level vs. time pattern.

4. Application examples

So far only situations have been studied with source and receiver on the same side of the forest. However, a major advantage of the current model implementation is that predictions are also feasible within the forest and on the opposite side of forest belts. Therefore this aspect shall be exploited in the application examples as well. Figures 5 and 6 show sound exposure maps for two situations with a forest belt of 50 m depth. In both cases a high barrier is present, once in the forest and once in front. In graphs b), depicting the forest reflection, the discretization of the super trees becomes visible. As can be seen in d), the forest reflections however are only dominant in the forest or in geometries were direct sound is shielded.

5. CONCLUSIONS

An engineering approach to calculate forest reflections has been presented. The calculation scheme describes the reflection of a single tree and models a number of representative trees, distributed over the entire forest. This areal approach allows predicting reflections inside and outside of forested areas, and yields also an exposure in the rear area. A verification with measurements yielded a generally good agreement with a standard deviation of 4 dB(A). Deviations are explained by varying forest properties and simplifications of the propagation calculation like the negligence of meteorological influences or the standardized ground-effect spectrum.

Simulations show that reflections from trees can become relevant primarily in situations where direct sound is shielded. Still pending is a validation of the model with independent measurements, the latter especially for receiver positions behind forest belts, where so far no measurements have been performed.

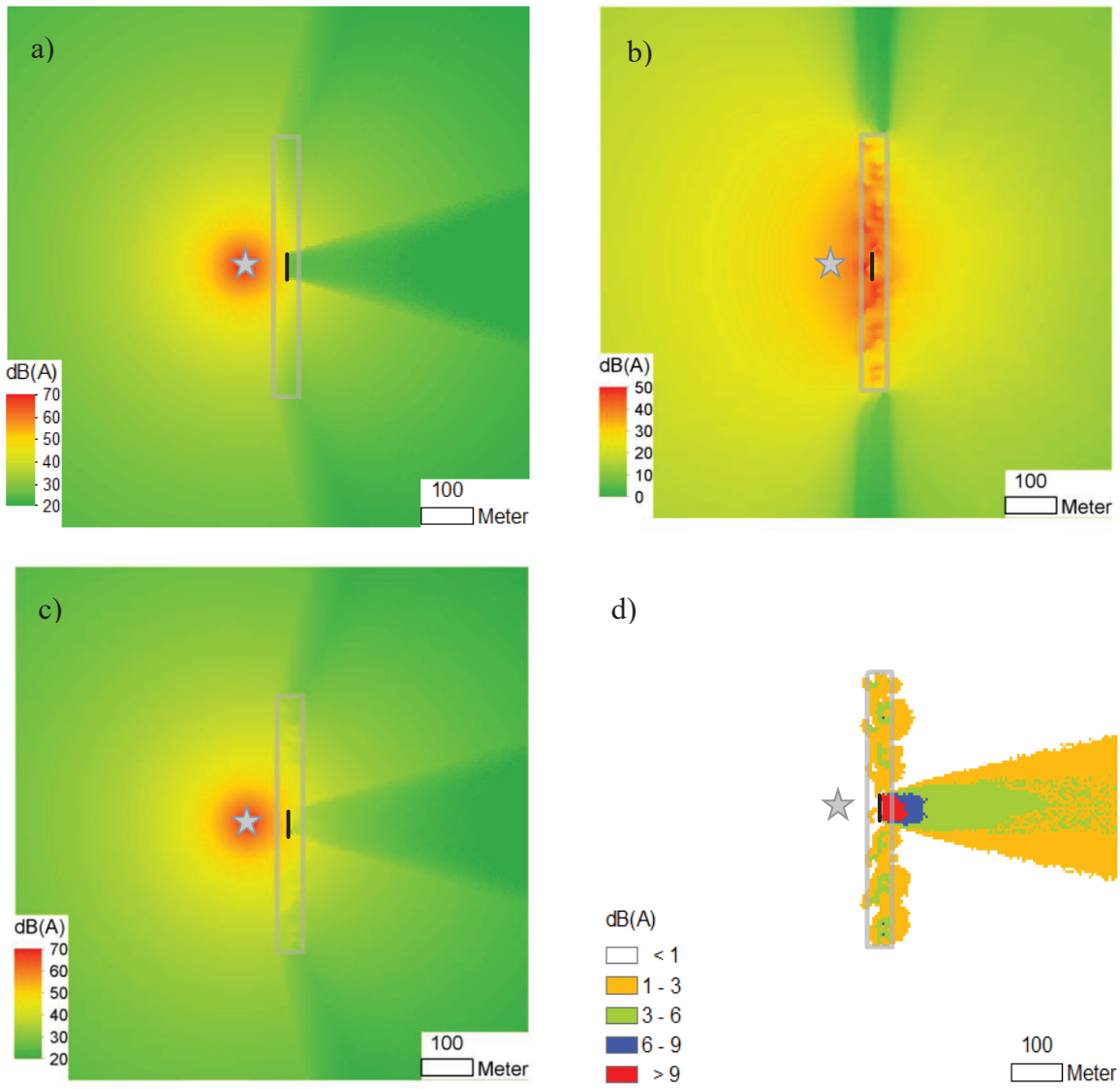

Figure 5 – Sound exposure maps with a 50 m deep forest of 500 m length and a barrier of 50 m length in the forest. a) Direct sound, b) Reflected sound, c) Direct and reflected sound, d) Level increase because of forest reflections.

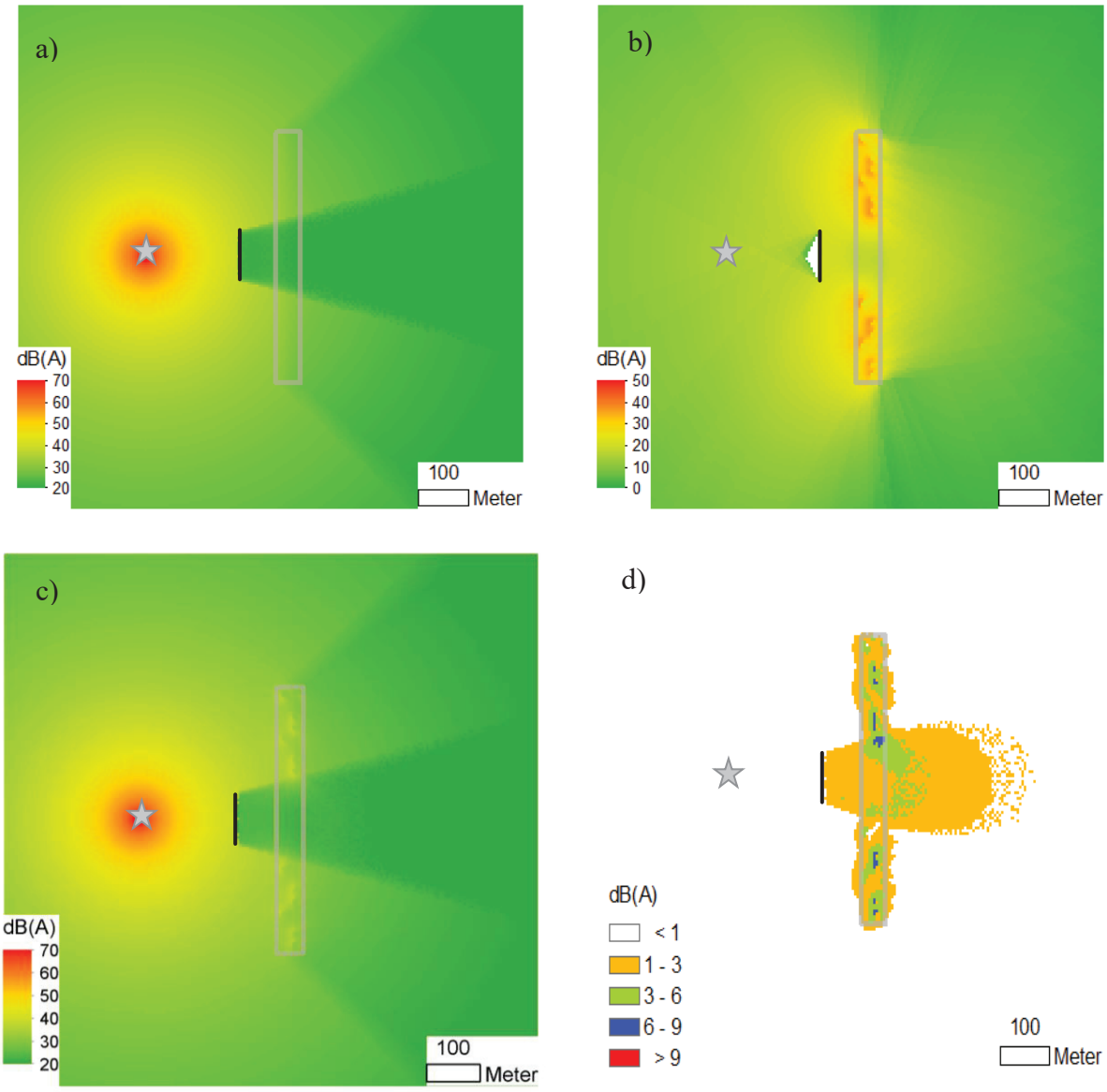

Figure 6 – Sound exposure map with a 50 m deep forest of 500 m length and a barrier of 100 m length in front of the forest. a) Direct sound, b) Reflected sound, c) Direct and reflected sound, d) Level increase because of forest reflections.

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