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UNDERWATER NOISE IMPACT OF OFFSHORE WIND FARMS DURING CONSTRUCTION AND OPERATION PHASES

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Abstract

The two potentially noisier phases of an offshore wind farm are construction and operation. During the construction phase, high noise levels are radiated to the environment, both in air and water, due to engineering works such as pile driving. In the operation phase, the acoustic power radiated by each wind turbine is much lesser, but their usual life-span is 20-25 years. The aim of this paper is to describe a normal mode propagation model designed to predict the underwater noise impact afforded for an offshore wind farm in both phases. The model needs as inputs the acoustic data of the underwater sources (power level and spectrum), the oceanographic data of the medium (sound velocity and density in water and sediments, wind speed, depth, acoustic spreading law in the area) and the coordinates of the wind turbines. As a result, the model provides both the 2D overall noise map around the farm or the overall noise level along a line, as compared to the background noise.

1. INTRODUCTION

The spectacular increment of electricity consum in Spain, with a growing of 38.5 % from 1998 till 2004, together with the restriction of CO_2 emissions imposed by the Kyoto protocol, demands for the use of alternative energy sources, such as wind energy. In 2004, 48.3 % of the electricity production in Spain came from fossil combustibles, as compared to 5.4 % from wind sources. Although governmental prevision estimated a wind power increasing from 8000 MW in 2004 to 14000 MW in 2011, some ecologist organizations claim for a greater increasing to 20000 MW.

One of the concerns expressed by the population about wind farms is its possible environmental impact. An alternative to the visual impact of land wind farms is the offshore wind farms. However, whilst the impact of the offshore wind farms in inhabitants is low, they can produce deleterious effects in the marine fauna of their environs. The aim of this work is to describe an acoustic propagation model elaborated to predict the underwater noise impact of the offshore wind farms in their surroundings.

The two noisier phases of a wind farm lifecycle are construction and operation [1]. The most significant activity during wind farm construction is foundation installation, specially pile driving. This activity can produce underwater peak levels as high as 271 dB re 1 μPa@ 1 m [2]. Whilst the operation phase is less noisy, it has a 20-25 year life span. Underwater source levels of 140-150 dB re 1 μPa @ 1 m have been reported in this phase [1].

Section 2 describes the propagation model accomplished for this problem. Some results for pile driving and operation activities are reported in Section 3 and 4, respectively.

2. UNDERWATER ACOUSTIC PROPAGATION MODEL

A propagation model has been derived, based on the normal mode theory, which samples the water column and solves the modal problem by using a finite difference scheme [3]. To solve this eigenvalue problem, two boundary conditions are needed: one for the water-air surface and other for the water-sediments interface. The scattering loss in the rough water-air surface is included by perturbing the normal modes as in Kupermann and Ingenito [4]. For the water-sediments interface, an elastic bottom is considered [5].

Figure 1 shows the geoacoustic model assumed. A water layer of constant depth, d, is considered, over an elastic bottom of constant depth, D, also. The water layer has a constant sound speed, c_w, and density, ρ_w. The sediment layer has constants density, ρ_b, compressional, c_{bp}, and shear, c_{bs}, sound velocities. The noise source is located in the middle of the water column. The wind velocity, V_w, and the spreading loss coefficient, m, in the medium are also input data of the model. Notice that each normal mode spreads as $(r)^{-m}$.

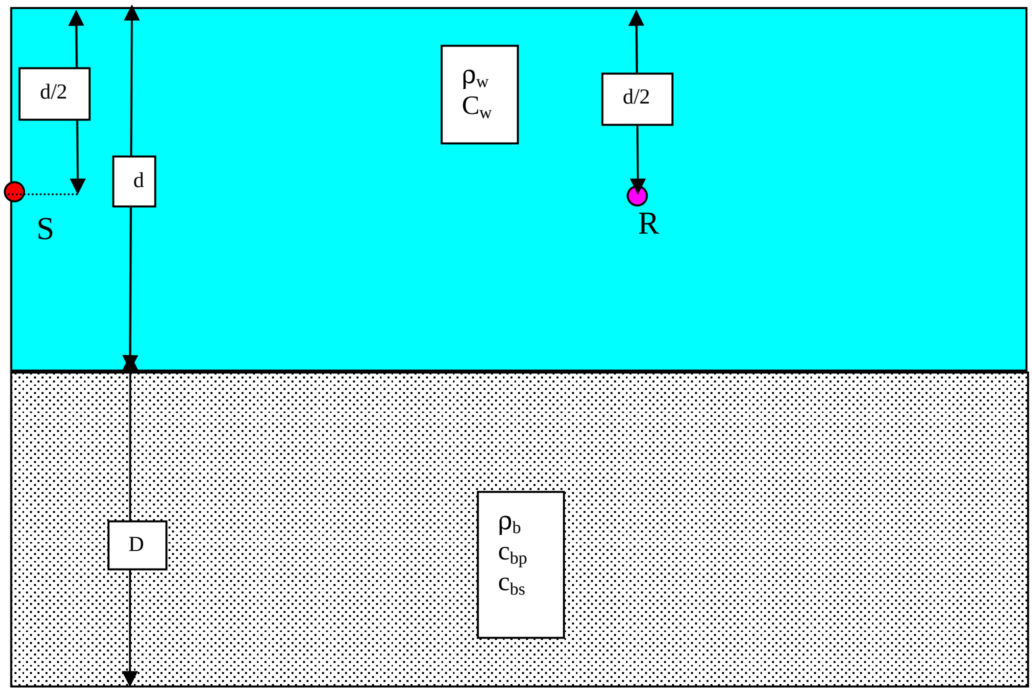

Figure 1. Geoacoustic model for underwater sound propagation

Once the location and source level of each turbine is given, the model propagates the noise to each point in a grid of the surroundings. Either spectral band or overall levels are afforded at mid depth and compared with the corresponding background band or overall levels. The output data can be given as 2D noise maps or sound pressure level versus range curves.

3. NOISE IMPACT DURING CONSTRUCTION PHASE

The pile driving noise depends on several factors such as the type of pile hammer (impact or vibro), the type of foundation (monopile or concrete) and the bottom hardness. In this paper, the spectral levels produced during pile driving have been taken from those measured by McKenzie Maxon in the construction of an offshore wind farm in Sweden [6]. Figure 2 shows the spectral levels measured by McKenzie Maxon at 320 m from the pile driving, the corresponding source levels at 1 m for spherical spreading, and the spectral levels of the background noise in a Spanish area where an offshore wind farm is planned. The overall source and background levels are 236 and 119 dB, respectively.

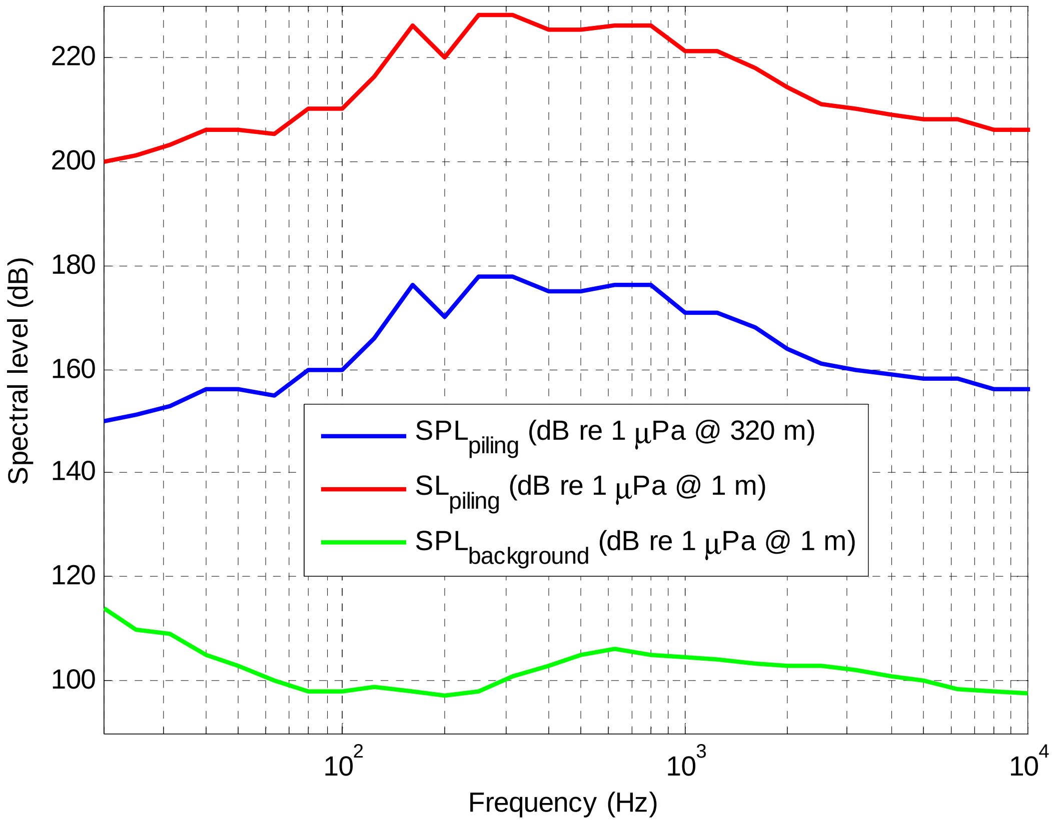

Figure 2. Sound pressure levels at 320 m (blue) and 1 m (red) of the piling activity as compared to the background noise in the area (green)

Figure 3 shows the overall noise map in the surroundings of the pile driving activity for d=15 m, D=50 m, ρ_w=1000 kg/m3, m=0.75, c_w=1487 m/s, ρ_b=2000 kg/m3, c_{bp}=1600 m/s, and c_{bs}=300 m/s. Figure 4 shows the spreading of the overall piling noise from the source, as compared to the background noise in the area. Since this Figure models sound propagation into a waveguide, the overall spreading loss differs of that of each mode. As it can be seen, the noise map shows a cylindrical symmetry. The overall piling sound pressure level surpasses the background noise in all the wind farm area. The piling noise exceeds the background noise in 78 dB at 1 km far from the source, and in 46 dB at 10 km. Since piling noise is wideband, it can potentially affect to the marine mammals in their high frequency range, where they have more sensitivity [1].

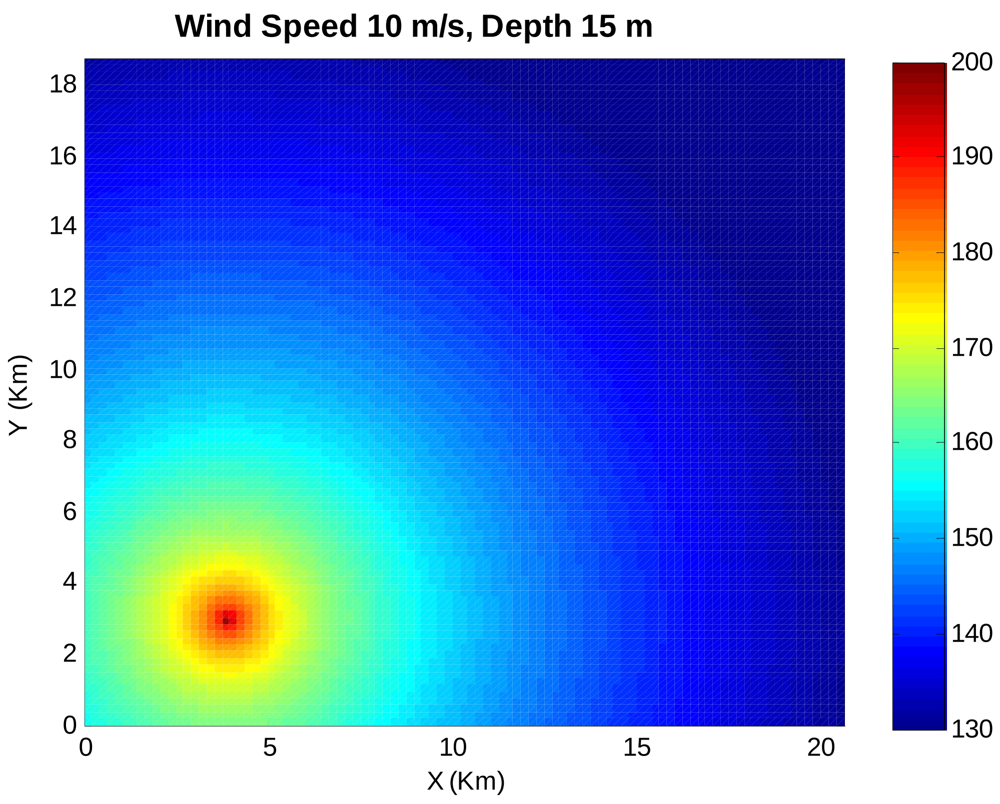

Figure 3. Overall noise map produced by piling activity in the area at half depth

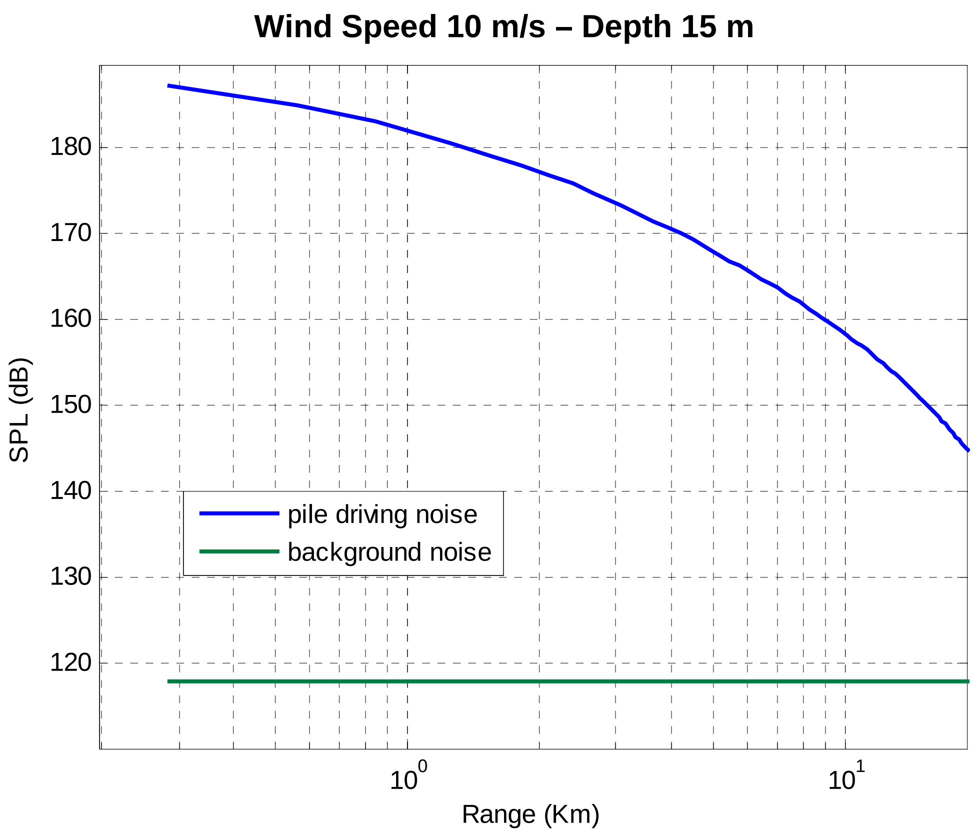

Figure 4. Spreading of piling noise (solid line) as compared to the background noise (dotted line) in the area

4. NOISE IMPACT DURING OPERATION PHASE

In this paper, the underwater spectral levels produced by a wind turbine during operational phase have been taken from those measured by Betke *et al.* [7] in an offshore wind farm in Germany. These measurements were made at 110 m far from a 1.5 MW turbine with spreading loss amounting for 15 log(R). Figure 5 shows these spectral levels, corrected for spreading losses, together with those of the background noise in the area. The overall source and background levels are 148 and 119 dB, respectively.

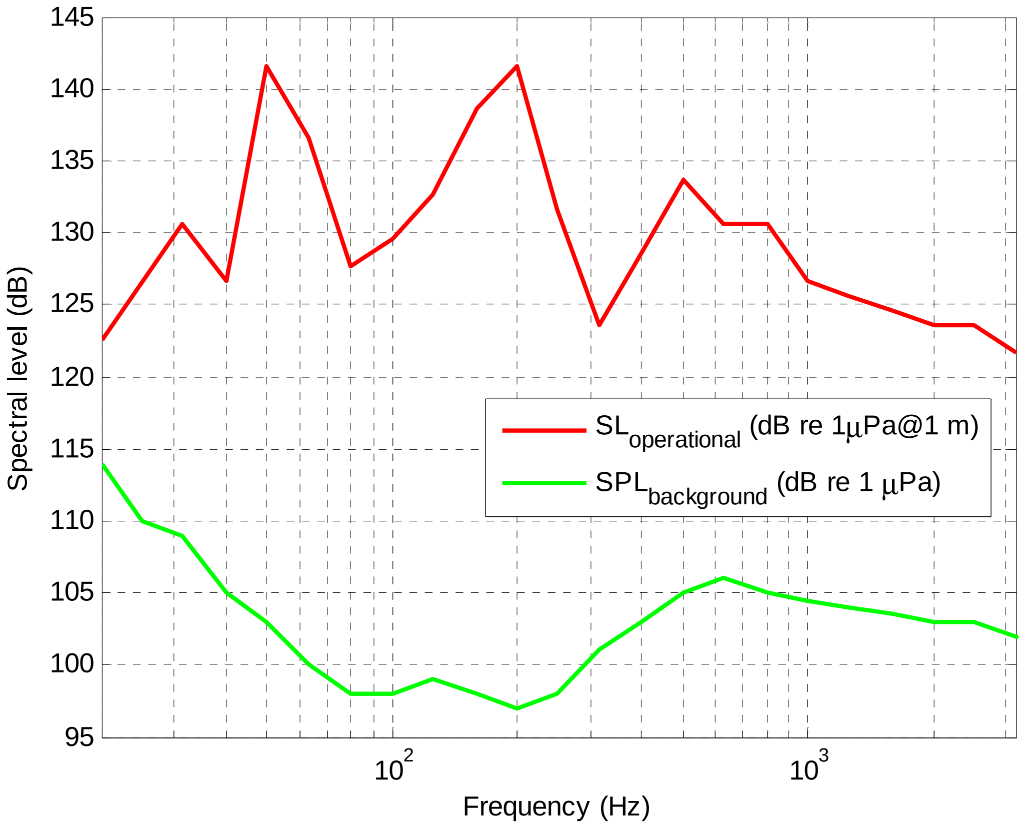

Figure 5. Spectral levels of operational noise (red) as compared to those of the background noise (green) in the area

Figure 6 shows the overall noise map in the surroundings of the wind farm for d=15 m, D=50 m, ρ_w=1000 kg/m3, m=0.75, c_w=1487 m/s, ρ_b=2000 kg/m3, c_{bp}=1600 m/s, and c_{bs}=300 m/s. Figure 7 shows the spreading of the overall operational noise along the shown line, as compared to the background noise in the area. As it can be seen, the noise map outlines well the pattern of the individual turbines. The overall operational sound pressure level is below the background noise in all the wind farm area, except for some small areas close around the individual turbines. Besides, the operational noise is higher in the low frequency range, where the marine animals have the lower sensitivity. Therefore, it can be expected than operational noise will have a low impact in the animal life of the surroundings.

6. CONCLUSIONS

To predict the underwater noise impact produced by an offshore wind farm, an underwater acoustic model is needed to extrapolate the source levels to each point in its surrounding.

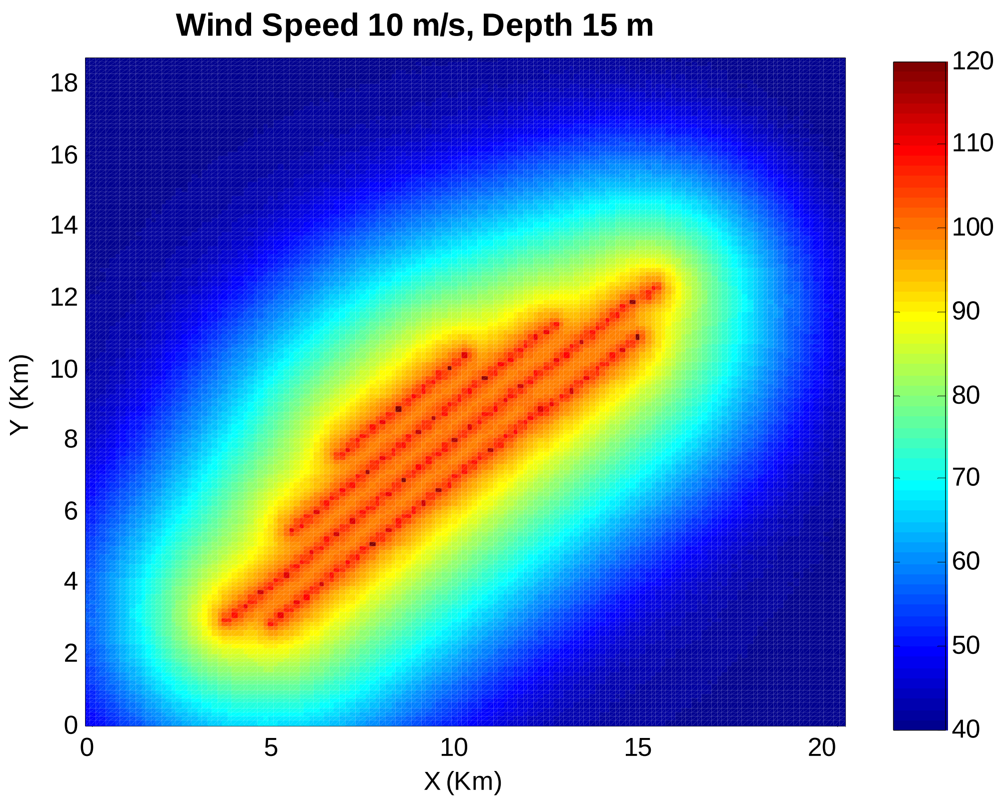

Figure 6. Map of the overall operational noise produced by 145 wind turbines in the area

In this work, a normal mode model is used to extrapolate the source levels into a water column with constant density and sound velocity. Both the source and the receivers are located at half depth of the shallow water column.

This model is used to predict the underwater noise impact of piling and operation phases of the wind farm. During pile driving, high source level, wideband noise is generated. For the source level of 236 dB re 1 μPa@1 m, reported by McKenzie Maxon, the piling noise exceeds the background noise in a large area (78 and 46 dB at 1 km and 10 km, respectively, from the source). Such high levels can produce severe effects in the marine wildlife around the wind farm, so that mitigation measures should be accomplished.

In the other hand, the operational phase of the wind farm produces a noise that scarcely exceeds the background noise level, with a spectral content rich in low frequencies, where the marine mammals have a low sensitivity. Therefore, this kind of noise should have a rather low impact in the marine wildlife.

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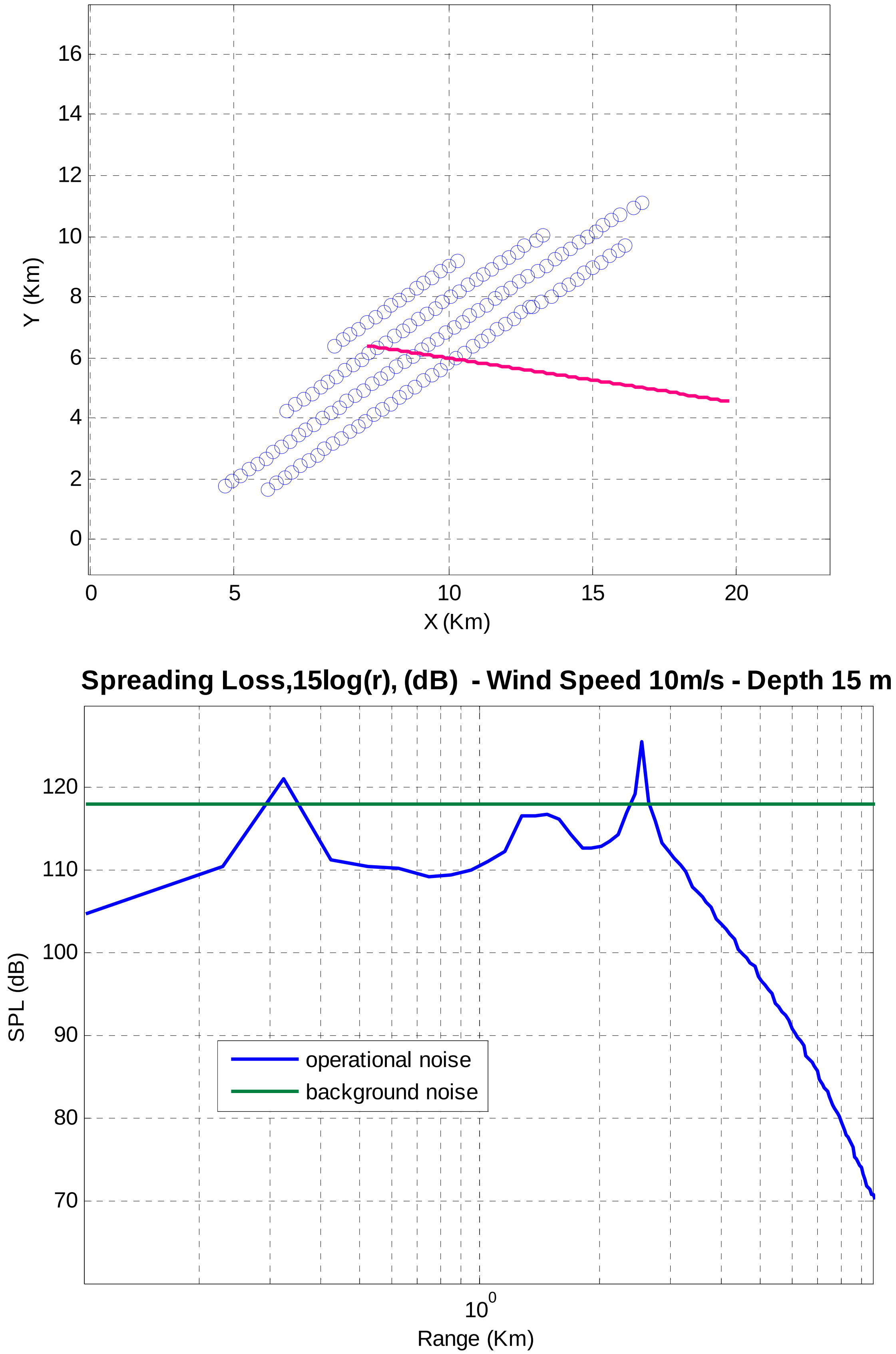

Figure 7. Spreading of overall operational noise (below) along the marked line (above)

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