Wind turbine noise prediction using Olive Tree Lab Terrain

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ABSTRACT

Calculation of noise propagation from wind turbines is complex, and large variations of sound immission levels are commonly observed at the same wind speed. These variations are influenced by sound emission (aerodynamic noise), but also by meteorological parameters such as temperature gradient, wind speed profile, wind direction, and turbulences. Commonly used models (ISO 9613-2 and Nord2000 for example) generally predict the average sound pressure levels adequately under downwind conditions, but often fail to predict noise levels in upwind conditions.

In this paper we present the results of the collaborative research between SIXENSE Environment (ex SOLDATA Acoustic) and P.E Mediterranean Acoustics Research & Development (PEMARD), using on site experience on more than 350 French windfarms, and Olive Tree Lab - Suite v4.0 software which uses wave based geometrical acoustics to calculate sound propagation, including atmospheric refraction. The goal is to combine both approaches and introduce and test key parameters for wind turbine noise prediction. Calculation results are compared to long term noise & meteorological measurements. A good correlation is shown between calculation and measurements even in case of complex meteorological situations.

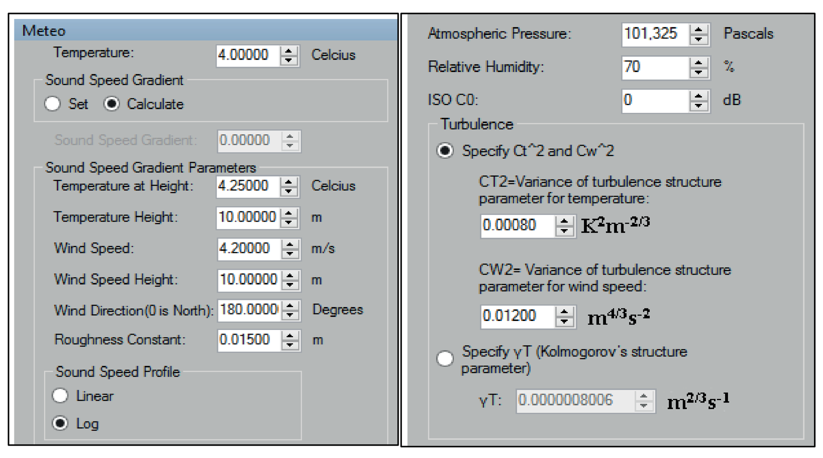
THEORETICAL BACKGROUND

The input parameters required to model a logarithmic sound speed profile in OTL-Suite are: the Temperature at ground level (*T*), the temperature at a height *z* defined by the user, the wind speed *u(zu)* at a height *zu*, the roughness constant *(z0)* and the wind direction *(φ)* defined in OTL-Suite as the clockwise angle from the North with the downwind condition blowing from south to north.In cases of a logarithmic sound speed profile the sound speed is described with the following equation :

$$c(z) = A \ln\left(\frac{z}{z_0}+1\right) + Bz + c_0$$

Where A and B are given by:

$$A = \frac{u(z_u)\cos\theta}{\ln\left(\frac{z_u}{z_0}+1\right)} \qquad B = \frac{dT}{dz}\frac{10.025}{\sqrt{T+273.15}}$$



Screenshot of the Meteo side panel in OTL-Suite

OTL-Suite employs the method by Harmonoise to approximate a logarithmic profile. (Plovsing, B; Kragh, J, 2006).

$$r_{A,B} = \frac{1}{\frac{1}{r_A}+\frac{1}{r_B}}$$

Where

$$r_A = sign(A)\frac{R}{8}\sqrt{\frac{2\pi c_0}{|A|}} \qquad r_B = sign(B)\sqrt{\left(\frac{c_0}{|B|}\right)^2+\left(\frac{R}{2}\right)^2}$$

The effective linear sound speed gradient can then be found using:

$$a = \frac{1}{r_{A,B}\cos\varphi}$$

Where φ is given by:

$$\varphi = \sin^{-1}\left(\frac{\sqrt{R^2+(z_r-z_s)^2}}{2r_{A,B}}\right) + \tan^{-1}\left(\frac{z_r-z_s}{R}\right)$$

R is the horizontal range between the source and receiver while z_s and z_r are the source and receiver heights respectively.

OUTLINE OF BENCHMARK CASES

For the present study the results of OTL-Suite were compared against the benchmarks cases in (Attenborough, et al., 1995) which we will refer to as the 1995 benchmark cases.

1995 Benchmark Cases; consist of four cases corresponding to different atmospheres:

- a homogenous atmosphere with uniform sound speed (Case 1),
- a non-homogenous atmosphere with a strong positive linear sound speed gradient of 0.1 (Case 2),
- a non-homogenous atmosphere with a strong negative linear sound speed gradient of -0.1 (Case 3)
- a composite sound speed profile (Case 4) which was not used as it exceeds the capabilities of OTL-Suite.

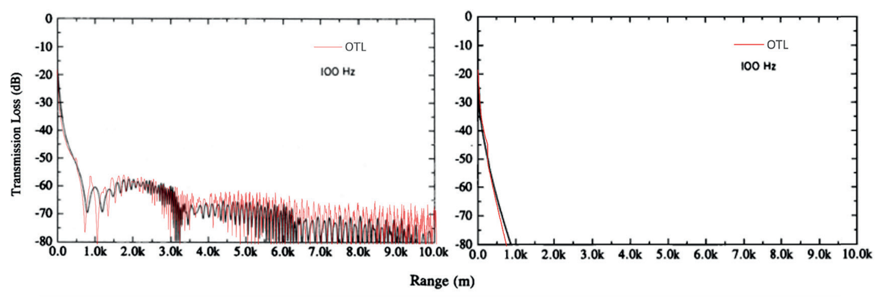
The ground impedance was described using the Delany and Bazley 1 parameter model with a Flow resistivity of 205000 Pa s m-2 as opposed to the 4-parameter model used in the benchmark paper.

Parameter	Value
Density of air (ρ_0)	1.205 kg/m^3
Atmospheric Pressure	1 atm
Relative Humidity (RH)	70 %
Temperature (T_0)	22 ºC
Ground Flow Resistivity (σ) (D&B)	205000 Pa s m^{-2}
Source Height (h_s)	5 m
Receiver Height (h_r)	1 m
Range (R)	10000 m
Frequency (f)	100 Hz

Parameters used for 1995 Benchmark Cases

RESULTS

1995 Benchmark Cases; Good agreement was found between OTL-Suite and the FFP, PE and analytical solutions used in the 1995 Benchmark Cases.

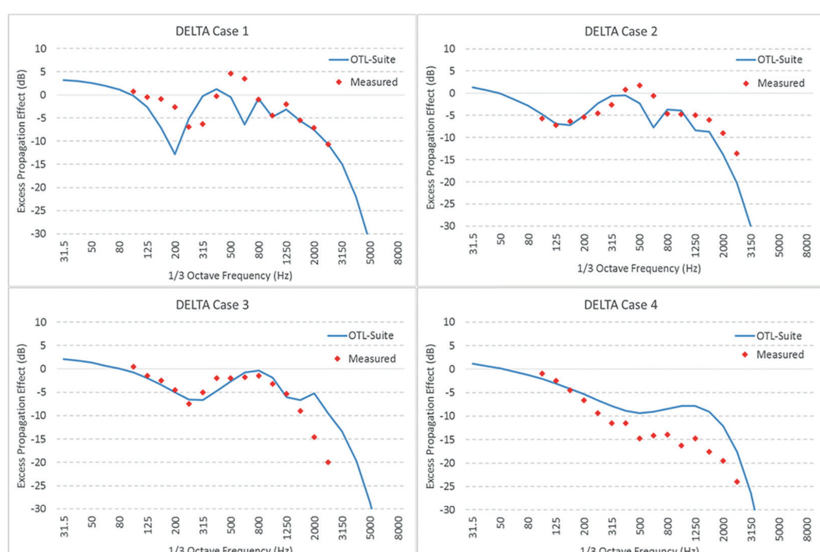


Comparison between OTL-Suite calculations (red line) and 1995 Benchmark Cases (black line).

Comparison with noise measurements

Parameter	Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4
Source Height (m)	50	50	50	50
Receiver Height (m)	2	2	2	2
Ranges (m)	456	1020	412	912
Temperature at Ground (ºC)	4	4	4	4
Temperature Height z (m)	10	10	10	10
Temperature at Height z (ºC)	4.25	4.25	4.25	4.25
Wind Speed Height z_u (m)	10	10	10	10
Wind Speed at Height z_u (ms^{-1})	4.2	4.2	4.2	4.2
Wind Direction relative to Sound Propagation Direction (degrees)	0 (downwind)	0 (downwind)	180 (upwind)	180 (upwind)
Roughness Constant (m)	0.015	0.015	0.015	0.015
Ground Flow Resistivity (Pasm^{-2})	400000	50000	50000	50000

Parameters used for the DELTA Validation Cases. Input data taken from (Plovsing & Kragh, 2009) or extrapolated from their graphical representations of the sound speed profiles. The ground Flow Resistivities were adjusted from DELTA's 200000 Pasm-2.



Measured and predicted excess propagation effect. Delta Cases 1 and 2 are for downwind conditions while Delta Cases 3 and 4 upwind conditions. The source receiver horizontal range is approximately 500 m for Cases 1 and 3 and approximately 1000 m for Cases 2 and 4.

Comparison with noise measurements around a wind farm

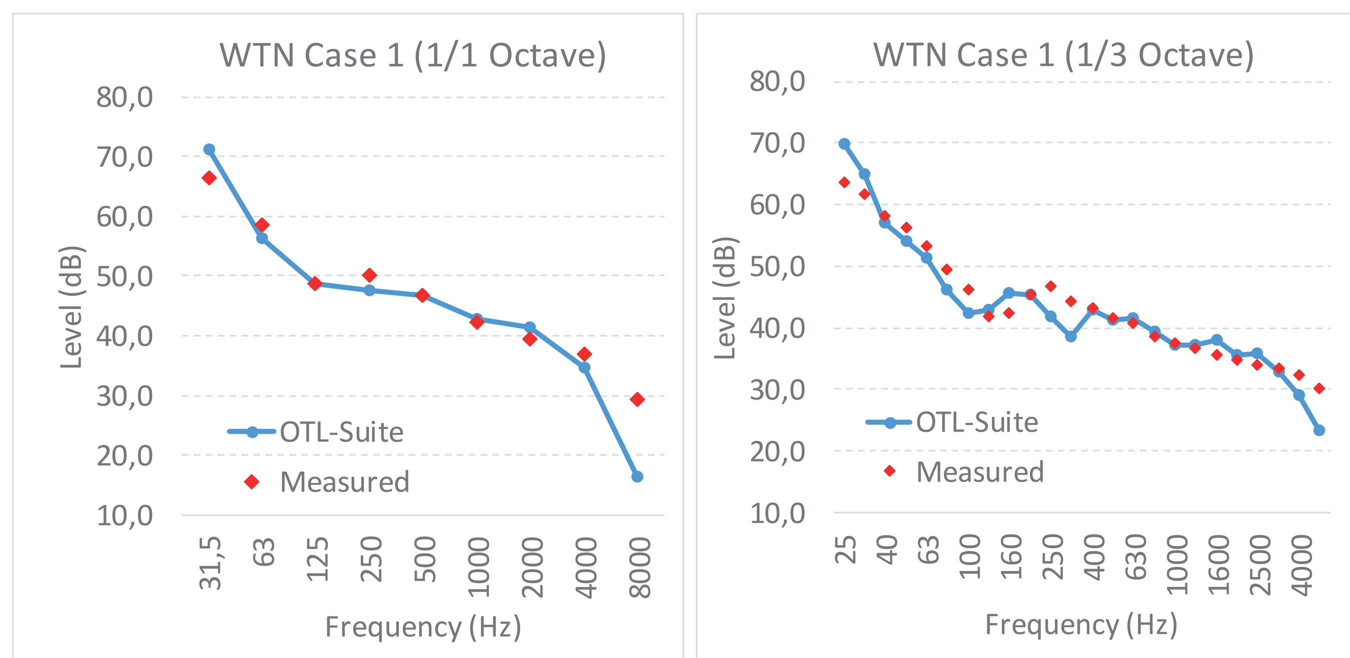
Parameters	WTN Case 1	WTN Case 2	WTN Case 3
Source Height (m)	80	80	80
Receiver Height (m)	1.5	1.5	1.5
Range (m)	150	500	500
Temperature at Ground (ºC)	10.7	4.1	3.6
Temperature Height z (m)	10	10	10
Temperature at Height z (ºC)	10.732	4.382	3.757
Wind Speed Height z_u (m)	10	10	10
Wind Speed at Height z_u (ms^{-1})	6.8	5.0	4.4
Wind Direction relative to Sound Propagation Direction (degrees)	Downwind	Downwind	Upwind
Roughness Constant (m)	0.05 (shear factor 0.16)	0.91 (shear factor 0.28)	1.33 (shear factor 0.31)
Ground Flow Resistivity (Pasm^{-2})	225000	225000	225000

Parameters used for OTL-Suite model to compare against WTN measurements

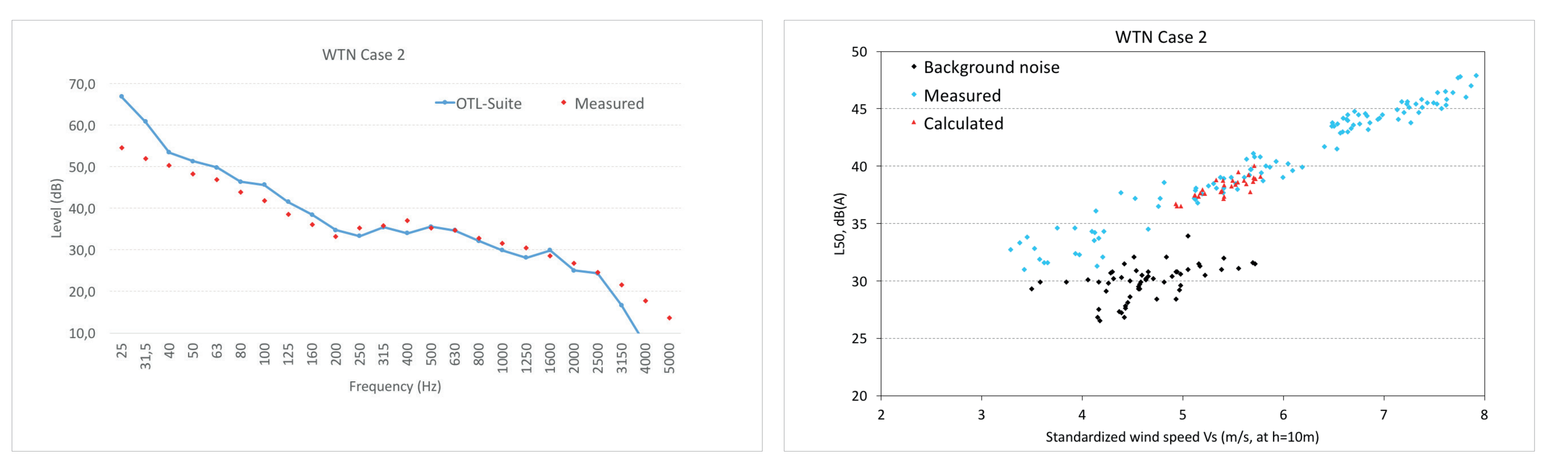
View of the 3D model for 3 wind turbines

RESULTS contd.

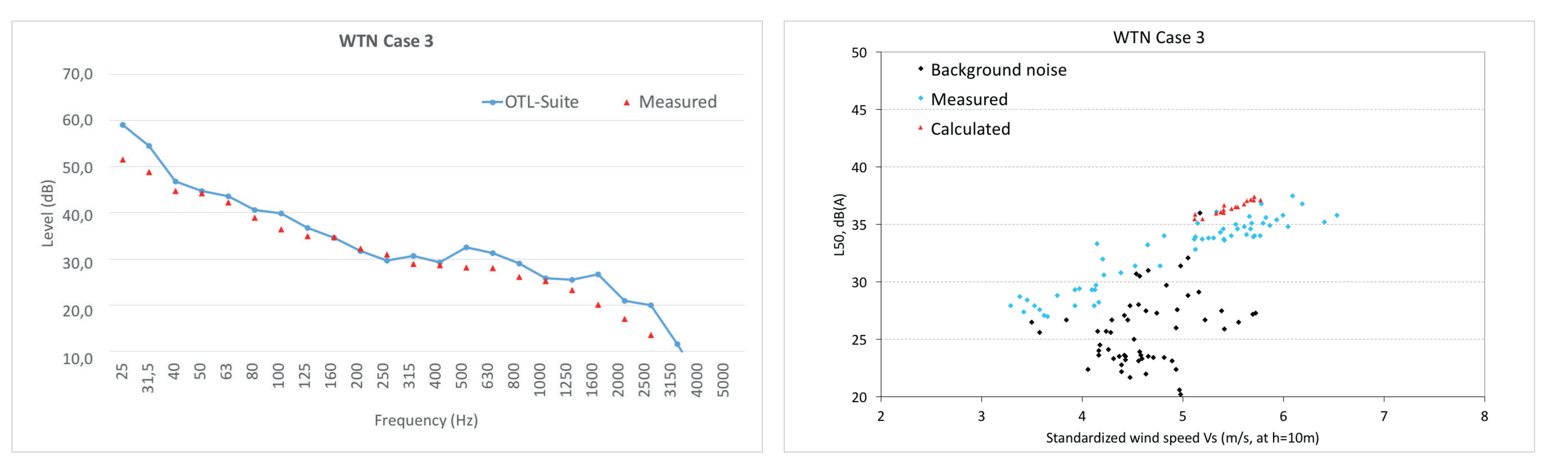
Noise measurements at h=1.5m



Measured and predicted noise level for WTN Case 1 in 1/1 band and 1/3 band. Downwind conditions with a range of 150m



Left graph : Measured and predicted noise levels for WTN Case 2. Right graph : Measured and predicted Noise Levels for Case 2 in dB(A) for a set of 10-minute meteorological data. Downwind conditions with a range of 500m.



Left graph : Measured and predicted noise levels for Case 3. Right graph : Measured and predicted Noise Levels for Case 3 in dB(A) for a set of 10-minute meteorological data. Upwind conditions with a range of 500m.

CONCLUSIONS

This paper is a result of a collaborative research between SIXENSE Environment and PEMARD. The calculation results of OTL-Suite are compared with benchmark cases and long term noise & meteorological measurements taken especially for this paper, at a wind turbine farm. Comparison of calculation results with benchmark cases is good. In the case of wind turbine noise there is a very good agreement in the downwind cases and acceptable results in upwind condition. The key point of the calculation is the knowledge of full meteorological data, including wind speed profile and temperature gradient.

The paper shows that the complexity of atmospheric dynamics cannot be fully represented by a single practical engineering model. The main source of discrepancy between measured and predicted data in ray models is the approximations used in calculating sound speed profiles. However, for engineering purposes accuracy has to be traded with calculation time. This being said, the ray models, implemented with multiple reflection paths, seem to be better suited as a compromise between accuracy and calculation time. Furthermore, sound ray paths allow for the visualisation of sound propagation.

PARTIAL LIST OF REFERENCES

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