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VARIABILITY AND UNCERTAINTY OF WIND FARM NOISE: A COMPARISON BETWEEN NUMERICAL PREDICTIONS AND IN-SITU MEASUREMENTS

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ABSTRACT

Wind farm noise depends on many environmental parameters that influence both sound emission and propagation. Poor knowledge of these parameters or their possible time and space fluctuations induce uncertainties leading to dispersion in SPL estimates. However, this dispersion is rarely taken into account, whereas it is not negligible realistic predictions. Thus, this paper presents a comparison between results of a model that estimates SPL dispersion of wind farm noise versus long-term experimental data. The uncertainty model is implemented in an open-access online tool (WindTUNE) developed within the French project PIBE. It is based on a metamodel embedded in a Shiny application, where noise emissions of each wind turbine of a wind farm are calculated using the Amiet's theory, and sound propagation is calculated using a wide-angle Parabolic Equation (WAPE) modelling. Experimental data come from observations collected within the PIBE project near a wind farm for over 400 days. Comparisons are carried out for several scenarios encountered during the experimental campaign, with various values of influential parameters. Finally, the paper provides information for the estimation of variability and uncertainty of wind farm noise, both numerically and experimentally.

Keywords: *wind turbine noise, uncertainty*

1. INTRODUCTION

The noise perceived by the neighborhood of a wind farm may show some variability over time, even at stationary wind speeds. The cause of this variability is very often related to the influence of local micrometeorology, which can affect both the sound emission at the blades and the sound propagation between the source and the resident, as well as to space and time variations in the ground properties. Thus, the PIBE Project[1] (2020-2024) aims to estimate these variabilities and the associated uncertainties.

Its objective is to enable engineering companies or wind farm developers to estimate more accurately the risk of noise annoyance in order to design a wind farm in an optimal manner. In the WP2 of the PIBE project, four approaches are explored: Estimation of uncertainties related to sound emission, estimation of uncertainties related to sound propagation, estimation of global/coupled

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[1] PIBE website: https://www.anr-pibe.com

uncertainties on noise predictions, experimental validation of the uncertainty model.

This paper focuses on both *(i)* the *numerical* approach through the presentation of the uncertainty model implemented in an open-access online tool called WindTUNE (Section 2), and *(ii)* the *experimental* approach through the presentation of an important in-situ measurements campaign (Section 3). The Section 4 gives a Conclusion and some perspectives for an original comparison between uncertainty estimation either numerical or experimental.

2. UNCERTAINTIES PREDICTIONS

The uncertainty model is implemented in a web application called WindTUNE[1] that will be open-access at the end of the PIBE project [1]. It is based on a metamodel [2] embedded in a Shiny application[2], where noise emissions of each wind turbine of a wind farm are calculated using the Amiet's theory [3], and sound propagation calculated using a wide-angle Parabolic Equation (WAPE) modelling [4].

2.1 User interface

The WindTUNE app gives access to the SPL dispersion of any wind farm project which hub height is close to 80m and rotor diameter close to 90m, and for receiver between 500m to 3 km from the wind farm. Locations of wind turbines can be easily implemented on a GIS map[3] through GPS coordinates, as presented on Figure 1.

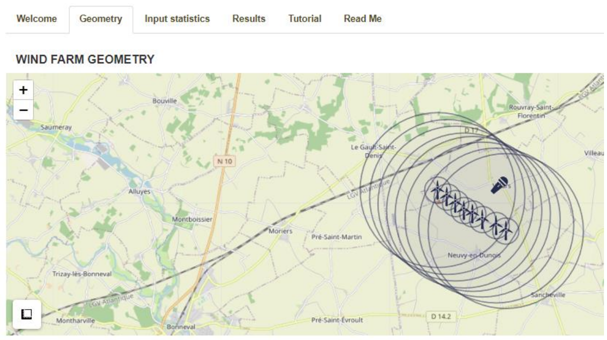

Figure 1. Wind farm configuration and receivers location (GPS coordinates) on the WindTUNE app.

2.2 Influential input parameters

Next, the WindTUNE user can set the variation range of several influential parameters, *e.g.* wind speed, air temperature, acoustic ground properties etc., with corresponding statistical distribution functions (uniform, Weibull, log normal, etc.), as described on Figure 2.

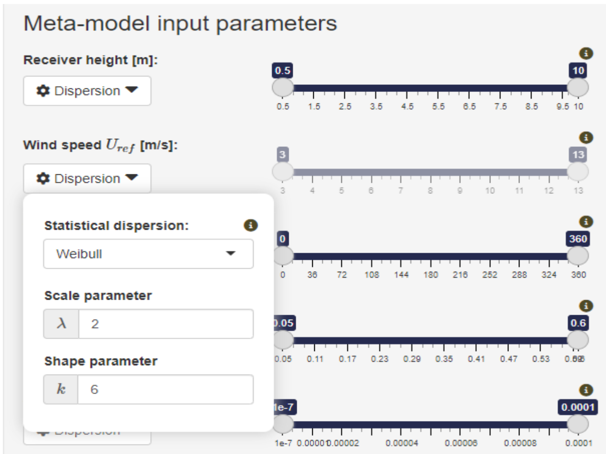

Figure 2. Range of variation and distribution of the influential parameters (input data) on the WindTUNE app.

2.3 Output: SPL dispersion

Lastly, the metamodel embedded in the WindTUNE app can directly estimate the SPL distribution for the considered case, either in third octave bands or for global A weighted SPL, normalized (*i.e.* centered) by the median value (see

[1] WindTUNE website: on line soon
[2] *Shiny* website: shiny.rstudio.com.
[3] OSM website: https://www.openstreetmap.org.

example on Figure 3). Thus WindTUNE app is a complementary tool for variability/uncertainty estimation which can be associated to an engineering tool for SPL impact study, for example an open source software such as *NoiseModelling*[1] or *Code_Tympan*[2].

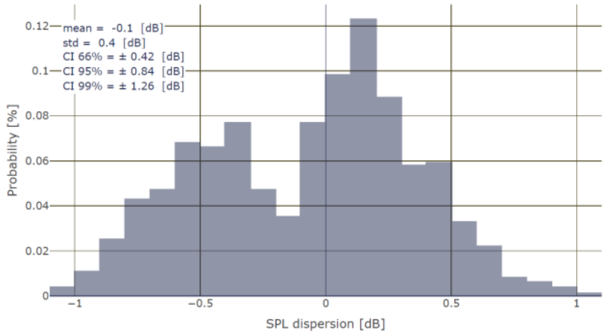

Figure 3. Example of output results (LeqA distribution) on WindTUNE app.

3. UNCERTAINTIES MEASUREMENTS

3.1 Experimental campaign

The experimental approach of the WP2 in PIBE project was carried out through the measurement campaign which took place on a wind farm, over 410 days from 01/02/2020 to 30/03/2021[6][7]. The wind farm site (located in France) was selected for the PIBE project because it offered several advantages/interesting features, *i.e* relatively recent and operational (wind turbines in operation), infrastructure fairly representative of common wind farms (8 wind turbines, hub height of 80m, blade length of 45m , power of 3MW), easy access to the site and to local power (for instrumentation), meteoroligical mast already present on the site (already equipped with several sensors and data acquisition devices, see Section 3.2 below), almost perfectly flat topography (which facilitates measurement/calculation comparisons), regular operation with a fairly marked North-South regime (alternating, to study upwind/downwind conditions), few interfering sound sources around (except trains and planes, see Section 3.3 below), relatively central geographically for the intervention of the different teams, etc.

[1]*NoiseModelling* website: noise-planet.org/noisemodelling.html.
[2] *Code_TYMPAN* website: sourceforge.net/projects/code-tympan.

3.2 Experimental protocol

The experimental campaign consisted in a continuous monitoring period based on acoustic and meteorological measurements thanks to various sensors: 5 sonometers and meteo stations dispatched on the site, 1 meteo tower, 1 wind LIDAR, SCADA wind turbines data (wind at hub, electrical production), etc. (see Figure 4 below).

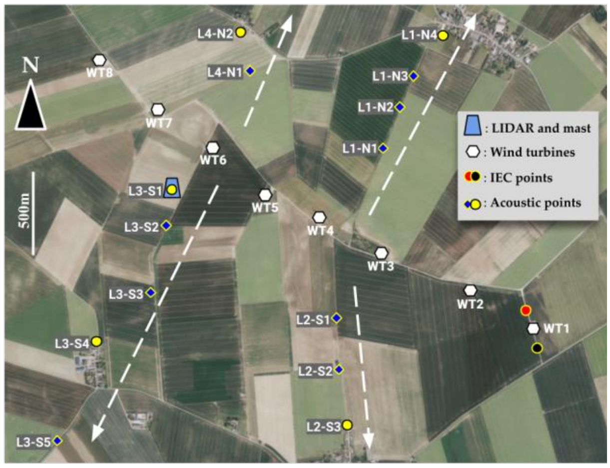

Figure 4. Experimental protocol of the PIBE campaign.

This long-term monitoring campaign has been completed by 2 intensive observations periods (IOPs) of 10 days each (in June 2020 and February 2021) with numerous additional devices on the experimental site: about 12 sonometers (including audio and low-frequency measurements), sound power of wind turbines (IEC protocol) and impedance measurements, etc. (see Figure 4 above).

Thus all periods taken together (monitoring+IOPs), the experimental protocol of this campaign aimed at characterizing/quantifying in situ a maximum of indicators related to acoustics and to the influential parameters, regarding both emission and propagation physical phenomena.

3.3 Data post-processing and validation

Acoustic and meteorological experimental data issued from the long-term measurement campaign have been post-treated to build a common standalone database thanks to Elasticsearch[1]. The database, in UTC timestamp, is structured and indexed by type of measurement (*acoustic*, *meteo*), sensor (sonometer *A1, A2*,…, *A5,* 3D ultrasonic anemometers *S1*, *S2* and *S3*, *TOWER*, *LIDAR*) and integration period of variables (*1min* and *10min*). Acoustic indicators concerns third octave bands ($L_{eq,f}$) and global A weighted SPL (L_{Aeq}) and statistical indicators (L_{10}, L_{50} and L_{90}) from 20Hz to 20kHz recorded with a 100-millisecond integration period by the 5 sonometers (*A1*,…, *A5*).

The data collected by the meteorological sensors (ultrasonic anemometers, tower and LIDAR) have also been post-treated to estimate meteorological variables over 1-minute and 10-minute integration periods among which temperature, wind speed and direction, relative humidity, rainfall and fog, as well as vertical gradients of temperature, wind and speed of sound.

The potential presence of extraneous noise (*i.e.* not associated with the wind farm) in the acoustic measurements have also been estimated for 3 different sources: (i) the passages of trains have been automatically detected using audio recordings located close to the railway near the wind farm; (ii) the passages of plane(s) have been manually referenced thanks to *FlightRadar*[2] by entering in a spreadsheet the date and time of aircraft arrivals in the area of interest; (iii) wind-induced noise at the windscreen microphones based on the measurement of the wind speed at the level of each microphone [5].

The *Elasticsearch* database has thus been supplied with all these data that can be requested by means of a specifically developed *Shiny* application (Figure 5).

Figure 5. Example of data visualization using *Elasticsearch* through the *Shiny* application.

The Figure 6 shows the time evolution of the overall A weighted SPL $L_{Aeq,1min}$ recorded by the 5 sonometers. One can note the lack of data in September 2020 due to a firmware bug.

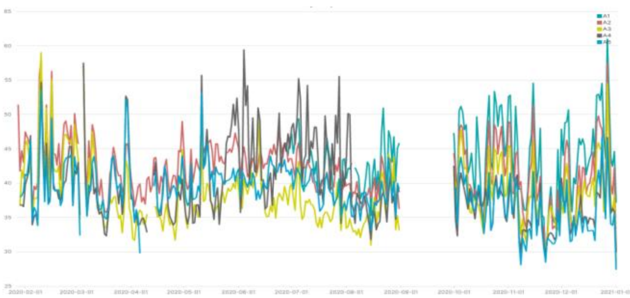

Figure 6. Evolution of the equivalent sound level $L_{eq,1min}$ recorded by the 5 sonometers from February 2020 to January 2021.

The Figure 7 illustrates the evolution of the temperature at the level of the meteorological tower at the 4 measurement heights. It may be noted that the data is erroneous at 20-meter high until the 4th June 2020.

[1]Elasticsearch website: www.elastic.co/fr/elasticsearch/.
[2]*FlightRadar* website: www.flightradar24.com.

Figure 7. Evolution of the temperature recorded at the tower at 6, 20, 60 and 78 m heights.

The Figure 8 presents the wind direction roses built from the data recorded by one of the three 3D ultrasonic anemometer at the meteorological mast.

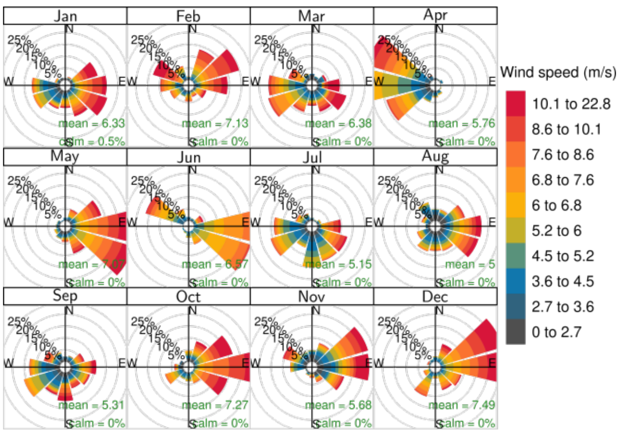

Figure 8. Monthly wind direction roses recorded by the 3D ultrasonic anemometer S3.

The Figure 9 gives an example of the potential presence of parasitic noise generated by the passages of train(s) and/or plane(s) or by the noise induced by the wind at the level of the microphones for the 1st week of August 2020.

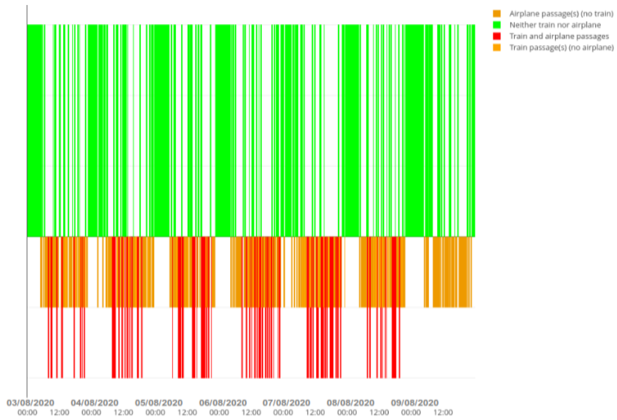

Figure 9. Illustration of the potential presence of parasitic noise in the acoustic measurements for the 1st week of August 2020.

4. CONCLUSION AND PERPSPECTIVES

This research work carried out within the PIBE project aims at estimating the dispersion of sound pressure levels issued from a wind farm, both numerically and experimentally. This has been carried out using dedicated tools, respectively: A *Shiny* application for the estimation of numerical predictions spreading from the metamodel, and another *Shiny* application (through *ElasticSearch*) for the visualization and analysis of SPL (and influent observables) measurements issued from a huge experimental campaign. The next step will consist in a direct comparison between numerical predictions and in situ measurements. This will be presented during the dedicated session at FA23, together with the presentation of the 2 *Shiny* applications which will be very useful for end-users.

5. ACKNOWLEDGMENTS

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