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A large-scale, long-term experimental campaign for the investigation of wind turbine noise fluctuations and amplitude modulation phenomena.

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ABSTRACT

The understanding and prediction of wind turbine noise (WTN) remain a subject on which progress is needed to better address the concerns of residents of some wind farms and to help wind farm operators to better optimize their wind farms. A large-scale and long-term measurement campaign was conducted by partners of the PIBE project (https://www.anr-pibe.com/en) near a French wind farm during 410 days, in order to study the emission and propagation of WTN. The campaign provided 100ms sound levels and acoustic spectra, together with periodically recorded 2 min audio samples, at 5 locations ranging from 350m to 1.3km from the wind farm, in different propagation directions. Meteorological data were simultaneously collected by a 80m meteorological mast, one or two Lidars and sonic anemometers, in order to characterize vertical profiles of wind speed, wind direction, temperature, and wind turbulence. 2 distinct weeks of intensive measurements (one in summer and one in winter) completed the data by including 15 additional acoustic points at other locations. The database will mainly be used within the project for the investigation of an uncertainty model of WTN, and of WTN amplitude modulations. This communication presents the database and first results about temporal variabilities of WTN.

1. INTRODUCTION

Wind energy industry is rapidly developing but the understanding and prediction of wind turbine noise (WTN) remain a subject on which progress is needed to better address the concerns of residents of some wind farms and to help wind farm operators to better optimize their wind farms production.

Noise from wind turbines can fluctuate over time for people living near wind farms, even if the wind speed is stationary. This is often due to the variability of the meteorology, which affects both the emission of noise from the blades and the propagation of sound between the source and the local residents, as well as to the temporal evolution of the acoustic properties of the ground. Currently, the acoustic impact studies of a wind farm project do not consider these phenomena, and there is no available information on the uncertainties of SPL predictions. Addressing this problem would enable wind farm developers to estimate more precisely the risk of noise annoyance and to design optimally their wind farms.

Developing an uncertainty model to predict these variabilities is one of goal of the PIBE project [1-2], and this model, based on an extension of the approach of Kayser *et al* [3], needs to be validated against field measurements. In this context, a large-scale and long-term measurement campaign was conducted by partners of the PIBE project near a French wind farm during more than one year. The goal of this campaign was to study the emission and propagation of WTN, and to get information on sound fluctuations or other specific events, like amplitude modulation, at local residents to better understand which and how environmental parameters influence those phenomena.

2. EXPERIMENTAL PROTOCOL

The wind farm where the measurements were made is located on the center of France, on a flat site (altitude gradient <1% over 3km), and is constituted of 8 wind turbines of 3MW nominal electrical power each. Each turbine has three 45m long blades, and a hub located at 80m high. The site has the advantage of a relatively quiet noise environment, a good diversity of wind speeds and directions, and the presence of a 80m high meteorological mast.

Acoustical measurements have been done at local residents in order to observe the evolution of noise levels during 410 days, from February 2020 to April 2021. This long-term campaign was completed by two shorter observation period of one week each, at 2 different seasons (July 2020 and February 2021), and involving supplementary acoustic and meteorological sensors in order to increase the spatial distribution of sensors.

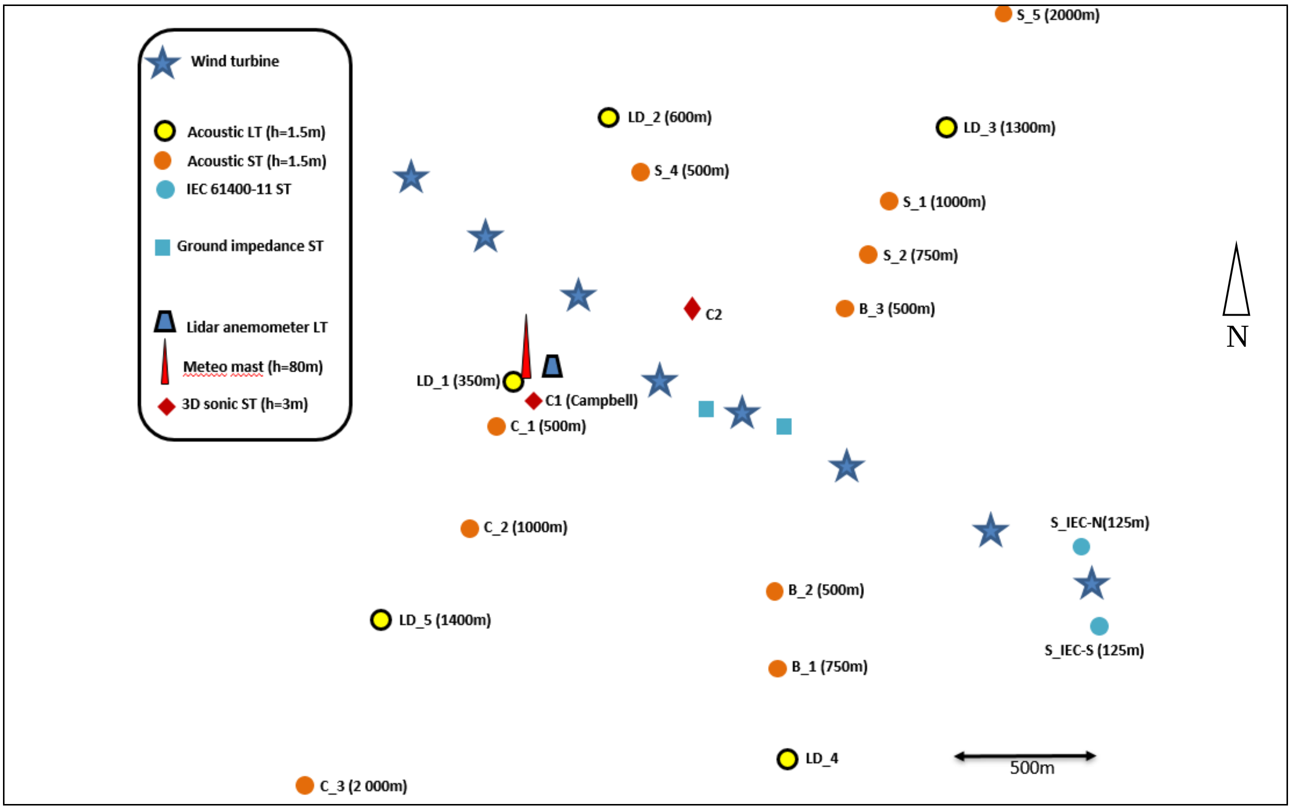

Figure 1: Experimental set-up with the location of the wind turbines and of the sensors installed during the long-term campaign (LT) and the short-term campaigns (ST).

2.1. Acoustical measurements

Long-term campaign

Five sound level meters were located on both sides of the wind farm (Figure 1) in directions corresponding to the predominant winds directions of the site, at distances -1400m, -1100m, -400m, +620m, +1300m from the wind turbine line ('+' and '–' notation account for South and North location respectively). This arrangement enables to measure simultaneously sound levels for upwind and downwind situations. The sound level meters (ACOEM Fusion) were placed at a height of 1.5m and recorded Leq(100ms) data in the frequency bands [6.3Hz ; 20kHz]. Each point also recorded a 2min audio signal every 10min. All data were automatically transfered each day to a remote server.

Short-term campaigns

During the two short-term campaigns, 10 additional sound level meters were placed at distances ranging from 500m to 2000m to the wind farm (Figure 1), both in upwind and downwind directions, to complete the spatial distribution of sensors during one week each time. The two furthest points at 2000m were equipped with sound level meters capable of measuring infrasound down to 1Hz or 6.3Hz, depending of the location.
Two measurements of the sound power level of one wind farm has been done following prescriptions of IEC 61400-11 [4]: for each point, a microphone was placed at ground level in the centre of a

circular reflective plate of 1m diameter, at a distance equal to the maximum height reached by the tip of a wind turbine blade, and equipped with two windscreens (9cm and 50cm diameter). The apparent sound power of the turbine is then obtained by correcting the measured sound level Leq for the attenuation due to the windscreen, the baffle effect of the plate, the geometric divergence and the atmospheric attenuation. The two IEC points were placed in opposite directions to each other in relation to the wind turbine, so that upwind and downwind conditions could be measured simultaneously.

Figure 2: IEC point

2.2. Meteorological measurements

Long-term campaign

A 80m high meteotological mast provided the following meteo data at several altitudes:

- temperature and relative humidity at 6m, 20m, 60m and 78.5m high;
- wind speed at 10m, 35m, 50m, 75m and 80m high;
- wind direction at 10m, 50m, 70m and 80m high;
- dew point temperature, atmospheric pressure and saturation vapor pressure, rainfall rate;
- wind turbulence data collected by three 3D ultrasonic anemometer (Young, 20Hz sampling frequency) located at 10m, 50m and 80m.

A Doppler Lidar anemometer (Zephir ZX300) measured wind speeds and wind directions at 11 heights ranging from 10m to 185m: 10m, 20m (under the bottom of the rotor), 39m, 55m, 70m, 85m, 100m, 115m (rotor), 130m, 145m, 185m (over the top of the rotor).

The Supervisory Control and Data Acquisition (SCADA) of the wind farm provided complementary meteorological data like wind speed and wind direction at the hub location of each wind turbine.

The five sound level meter of the long-term campaign were equipped with a local meteorological station in order to provide wind speed and wind direction close to the microphone and at the same height of it. This information is useful to estimate the wind noise contribution at the microphone level and for discarding data that is too polluted by wind noise.

Short-term campaigns

Two supplementary 3D ultrasonic anemometer (Campbell) were added at two different locations (C1 and C2, Figure 1). They measured wind speed and wind direction at a height of 3m in the vertical and horizontal planes, with a sampling rate of 20Hz. After processing the data, these equipments allow the determination of the vertical wind and temperature profile using the Monin-Obukhov similarity theory [5,6]. The vertical gradients of wind speed and temperature obtained make it possible to determine the vertical gradient of the sound speed.

Figure 3: Meteorological apparatus. Sonic anemometer (left), meteo mast (middle), LIDAR (right)

During the second short-term campaign (winter), a second Doppler LIDAR anemometer (Leosphere Windcube) has been installed at the same distance to the wind farm than the first LIDAR but on the opposite direction, in order to measure simultaneous wind data profiles upwind and downwind, to gather information on the wake effect wind turbine on sound propagation.

2.3. Additional measurements

The campaign was carried out on an agricultural site divided into several cultivated fields. As a result, the soil properties (roughness height and length, characteristic impedance) were not homogenous over the entire acoustic propagation domain. As the properties of the ground are a major influencing characteristic on the sound levels encountered [7], acoustic impedance measurements were carried out once a month at several points of the site (Figure *4*) using an in situ acquisition and processing system developed in partnership between Ifsttar/Cerema [8,9].

Figure 4: Experimental set-up for the measurement of ground acoustic impedance of three grounds

The SCADA of the wind farm provided several additional data on the wind turbines operations (electricity production, rotor orientation, blade pitch, etc.).

4. POST PROCESSING AND DATABASE CREATION

The large amount of data collected (>7 To) has been gathered in a structured database that will be freely available on internet after the end of the PIBE project. Several specific treatments have been done on data in order to provide with the database several quality index associated with each data:

- a quality index on the noise contribution of the wind noise contribution at the microphone, by calculating the uncertainty due to the wind noise on a screened microphone following the method described in [10];

- a quality index on the probability of presence of WTN in acoustical measurement, estimated by detecting low frequency peaks in the infrasound part of the measured spectrum [11];
- Modulation amplitude events detection, following the IOA protocol [12].

In order to effectively handle the database, it has been interfaced with the search engine Elasticsearch which is dedicated to efficient web datamining [13]. This web engine is based on the Lucene library and provides a distributed, multitenant-capable full-text search engine with an HTTP web interface and schema-free JSON documents. An example of the web application, is given in Figure 5 .

Figure 5: Example of the web interface for experimental

4. CONCLUSIONS

As part of the PIBE project, a long-term measurement campaign was carried out at a French wind farm, in order to collect information on noise fluctuations and their causes. The long-term campaign allowed to record during 440 days more than 57 million sound levels and 100ms acoustic spectra [6.3 Hz; 20kHz] for the 5 points distributed between 350m and 1.3km around the wind farm, associated with 10min meteorological data (vertical profiles of wind speed and direction, vertical profile of temperature, vertical profile of wind turbulence) and data related to the operation of wind turbines (electrical production, operating parameters of wind turbines ...).
The purpose of the measurements will consist in particular in comparing the uncertainties of the sound pressure levels measured with those estimated by the reference model and which will have been previously fed by the uncertainties observed on the main influence parameters (ground, meteorology, etc.) during the measurement period.
The database will finally be available to the scientific community *via* an Internet page after the end of the PIBE project.

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