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UPWARDS

Deliverable D4.6

Numerical database of wind farm benchmark

WP	4	Flow and acoustic simulations
Task	4.4	Wind farm noise/annoyance benchmark

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[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

[2] Nature of the deliverable: **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

[3] Creation, modification, final version for evaluation, revised version following evaluation, final

Deliverable abstract

The numerical noise database produced in the UPWARDS project is described in the present deliverable in terms of publicly released files and respective variable content. The benchmark consists in a reduced layout of nine wind turbines located in the Høgjaeren wind farm in Norway for two wind conditions of similar wind speed amplitude but having opposite wind directions. The necessary information for the user to produce the noise footprint on an observer grid are detailed.

Deliverable review

	Reviewer #1: /Coordinator			Reviewer #2:		
	Answer	**Comments**	**Type***	**Answer**	**Comments**	**Type***

1. Is the deliverable in accordance with

(i) The Description of Work?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☐ Yes ☐ No		☐ M ☐ m ☐ a
(ii) The international State of the Art?	☐ Yes ☐ No	*Not applicable for this deliverable*	☐ M ☐ m ☐ a	☐ Yes ☐ No	*Not applicable for this deliverable*	☐ M ☐ m ☐ a

2. Is the quality of the deliverable in a status

(i) That allows it to be sent to European Commission?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☐ Yes ☐ No		☐ M ☐ m ☐ a
(ii) That needs improvement of the writing by the originator of the deliverable?	☐ Yes ☒ No		☐ M ☐ m ☐ a	☐ Yes ☐ No		☐ M ☐ m ☐ a
(iii) That needs further work by the Partners responsible for the deliverable?	☐ Yes ☒ No		☐ M ☐ m ☐ a	☐ Yes ☐ No		☐ M ☐ m ☐ a

* Type of comments: M = Major comment; m = minor comment; a = advice

Table of content

1 Introduction

The present database is related to the noise produced by a reduced number of wind turbines located in the Høgjaeren wind farm, as described in details in Sec. 2. In order to obtain the resulting noise maps for trailing-edge noise on an observer grid located around the reduced wind farm center, the methodology developed during the UPWARDS project has been applied. Two different approaches have been developed, as shown in Figs. 1 and 2, and are based on a weather reforecast with an atmospheric flow model at a particular time instant, and used as input of the methodology. Further details on the available input files are given in Sec. 3.

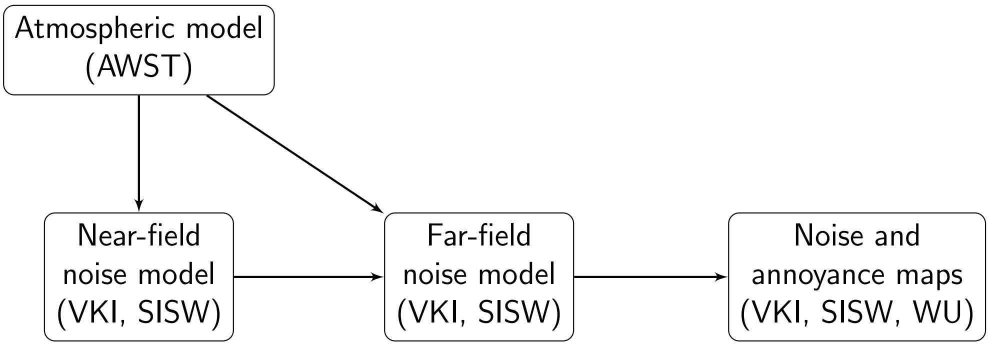

Figure 1: Noise model based on WRF.

In the first method, the atmospheric flow data are used as input to the near-field noise model relying on a strip theory implementing Amiet's theory for trailing-edge airfoil noise [2]. In order to compute the necessary inputs, a two-dimensional RANS-based approach [1] is adopted taking its input from the Atmospheric model. The long-range propagation of the point noise sources computed in the previous step is then calculated using a ray-based acoustic approach. This approach accounts for effects of the ground reflection as well as refraction due to velocity/temperature gradients present in the atmospheric boundary layer. The effect of atmospheric flow and terrain are taken into account thanks to a coupling between the noise model and the Atmospheric model.

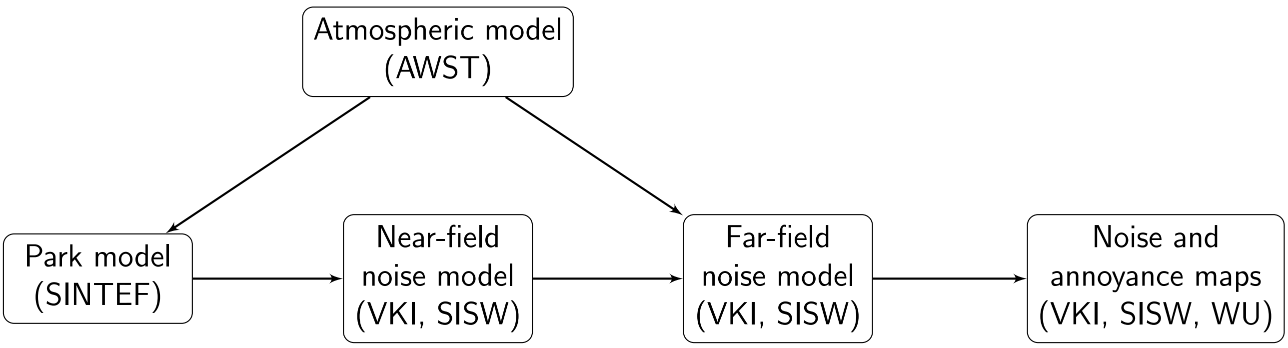

Figure 2: Noise model based on WRF and Park.

In the second method, an extra step is added between the atmospheric model and the near-field noise model as shown in Fig. 2. A Park simulation, based on Actuator Line Model, taking as input

[1] RANS: Reynolds-Averaged Navier-Stokes simulation.

the atmospheric flow data is used to simulate the interaction of the wind turbines with the atmospheric boundary layer as well as the interaction between wind turbines. This allows to have a more realistic input flow description for the noise predictions of downstream wind turbines as the interaction of the wake of upstream wind turbines is now properly modelled.

Further details on the different methods depicted in Figs. 1 and 2 are reported in the publicly available Deliverable D4.5 of the UPWARDS project.

2 Description of the wind farm benchmark

The Høgjaeren wind park [1], located in southern Norway as shown in Fig. 3 (a), is selected for the present benchmark. This wind farm contains 32 wind turbines with a total capacity of 73 MW and an annual production of 230 GWh. A subset of 9 wind turbines, shown in Fig. 3 (b), has been selected to maximize interactions between the wind turbine for any wind direction compared to other subsets of the wind farm. The corresponding wind turbine positions are reported in Tab. 1 in WGS coordinates. This subset has wind turbines of type SWT2.3MW-93, that has been used in the validation work performed during the UPWARDS project and based on the publicly available benchmark [3]. For the present benchmark, the same wind turbine geometry and operating conditions have been used [3].

(a) (b)

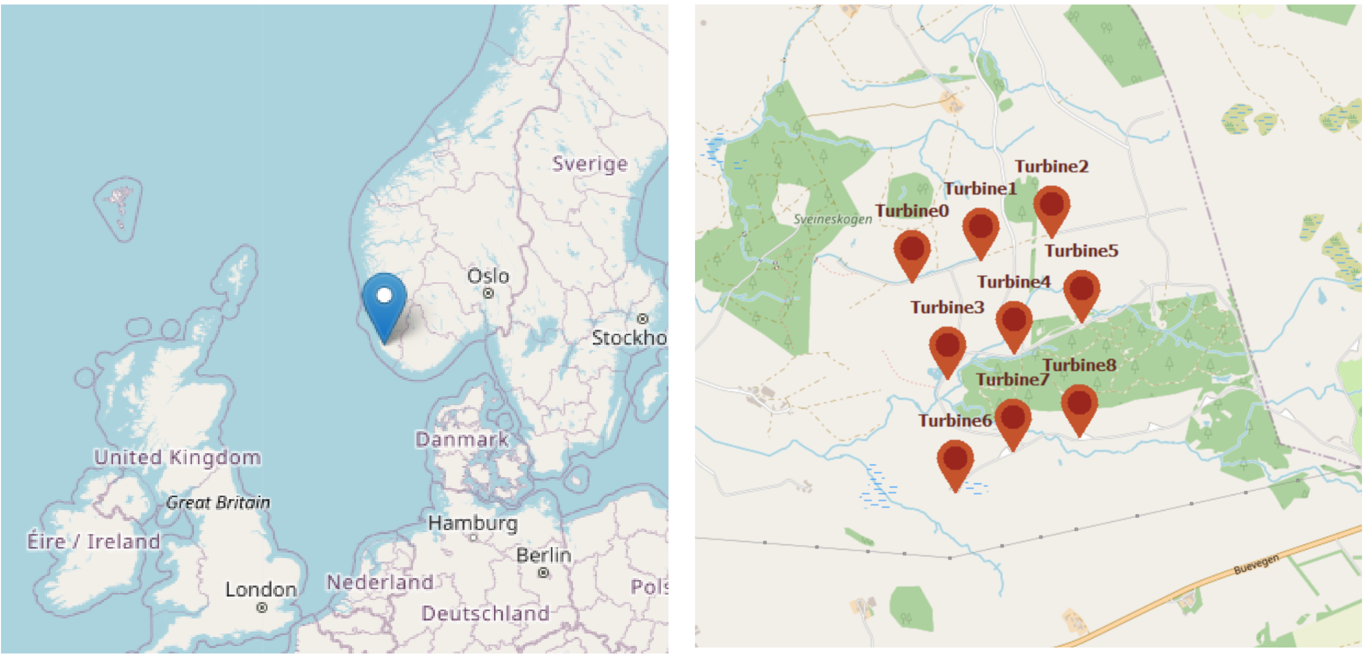

Figure 3: (a) Location of the Høgjaeren wind park and (b) subset of selected wind turbines for the present study.

Two different wind conditions are selected based on the meteorological data available near the wind park, looking for a wind amplitude of 10 m/s and two opposite wind directions. This results in the following cases:

- **South-East case**: 30^{th} Dec., 2017, referred later as SE case
- **North-West case**: 12^{th} Jun., 2018, referred later as NW case

For both cases, the atmospheric flow data are averaged over the period between 00:00 to 01:00 hour, and used as input to the Park or noise methods.

Turbine #	Lat	Lon
0	58.6479352	5.7351223
1	58.6488283	5.7404438
2	58.6497231	5.7459104
3	58.6440498	5.7378689
4	58.6450547	5.7430187
5	58.6463259	5.7482145
6	58.6394867	5.7384188
7	58.6411617	5.7428820
8	58.6417200	5.7480318

Table 1: Wind turbine positions considered for Høgjaeren wind park benchmark.

Four noise simulations are carried out for the Høgjaeren wind farm. Their main input and output files are shown in Tab. 2. The simulation names are defined such that *ATM* corresponds to the only use of the Atmospheric model as input to the noise methods as defined in Fig. 1 and *ATM-Park* corresponds to the use of both the Atmospheric and the Park models as inputs as defined in Fig. 2. As mentioned above, SE and NW correspond to the **South-East case** and **North-West case**, respectively.

case	simulation name	input file	output file
1	ATM-SE	wrf_SE_2017-12-30_01_00.nc	Spp_ATM-SE_observer_grid.nc
2	ATM-NW	wrf_NW_2018-06-12_01_00.nc	Spp_ATM-NW_observer_grid.nc
3	ATM-Park-SE	wrf_SE_2017-12-30_01_00.nc	Spp_ATM-Park-SE_observer_grid.nc
4	ATM-Park-NW	wrf_NW_2018-06-12_01_00.nc	Spp_ATM-Park-NW_observer_grid.nc

Table 2: Input and ouput files used in the numerical simulations for Høgjaeren wind park.

3 Description of available data

This section describes the variables contained in the input and output files mentioned in Tab. 2, and shows examples of plots that can be reproduced using the python scripts provided in the database.

3.1 Weather input file

The time-averaged atmospheric flow data are provided as input in netCDF format. Data are provided for a rectangular region surrounding the subset of 9 wind turbines. Two files are provided namely, "wrf_SE 2017-12-30_01_00.nc" and "wrf_NW 2018-06-12_01_00.nc", corresponding to the **South-East case** and **North-West case**, respectively. Each file contains the variables listed in Tab. 3. The data are defined with respect to the Easting-Northing UTM coordinates (X,Y) and the height above the ground Z. The grid dimensions are equal to $N_x = 108$, $N_y = 108$ and $N_z = 24$ for the two data files. These coordinates correspond to equally-spaced longitude and latitude WGS-84 coordinates (lon, lat). The dataset contains the wind speed vector $[U, V, W]^T$, the terrain elevation above mean sea level TOPO, the turbulence intensity TI, the air temperature T, the relative humidity RH and the nature of the terrain LAND_USE. The nature of the terrain LAND_USE is defined by the Summer-Winter averaged land use categories listed in Tab. 4.

Variable	Description	Dimension	Type	Unit
lon	Equally spaced longitude coordinates	N_x	float32	$^\circ$
lat	Equally spaced latitude coordinates	N_y	float32	$^\circ$
height	Coordinates in ground-normal direction	N_z	float64	m
X	Easting UTM coordinates	$N_y \times N_x$	float64	m
Y	Northing UTM coordinates	$N_y \times N_x$	float64	m
Z	Height above the ground	$N_z \times N_y \times N_x$	float64	m
LON	Longitude coordinates	$N_y \times N_x$	float32	$^\circ$
LAT	Latitude coordinates	$N_y \times N_x$	float32	$^\circ$
TOPO	Terrain elevation above mean sea level	$N_y \times N_x$	float32	m
LAND_USE	Summer-Winter land use category	$N_y \times N_x$	categorical	-
U	Wind speed in X-direction	$N_z \times N_y \times N_x$	double	m/s
V	Wind speed in Y-direction	$N_z \times N_y \times N_x$	double	m/s
W	Wind speed in Z-direction	$N_z \times N_y \times N_x$	double	m/s
TI	Turbulence intensity	$N_z \times N_y \times N_x$	double	-
T	Air temperature	$N_z \times N_y \times N_x$	double	C
RH	Relative humidity	$N_z \times N_y \times N_x$	double	-
projected UTM zone	UTM zone	1	integer	-
projected UTM letter	UTM letter	1	letter	-
central_coordinates_UTM	WRF central UTM coordinates (east,north)	1×2	float64	$^\circ$
central_coordinates	WRF central WGS coordinates (lat,lon)	1×2	float32	m

Table 3: Description of time-averaged weather input data stored in netCDF files.

A python script *read_wrf_data.py* to read the weather input file is provided in the database. The script gives some examples of data plots, as shown in Fig. 4 for the terrain elevation and wind speed U at a given height of 5.6 m. The data contained in the netCDF file can also be easily loaded in visualization software like Paraview or Tecplot.

3.2 Acoustic output file

The acoustic results of the method briefly described in Sec. 1 and in D4.5 are provided in netCDF format. Data are provided on a rectangular cartesian grid surrounding the subset of 9 wind turbines. Each file

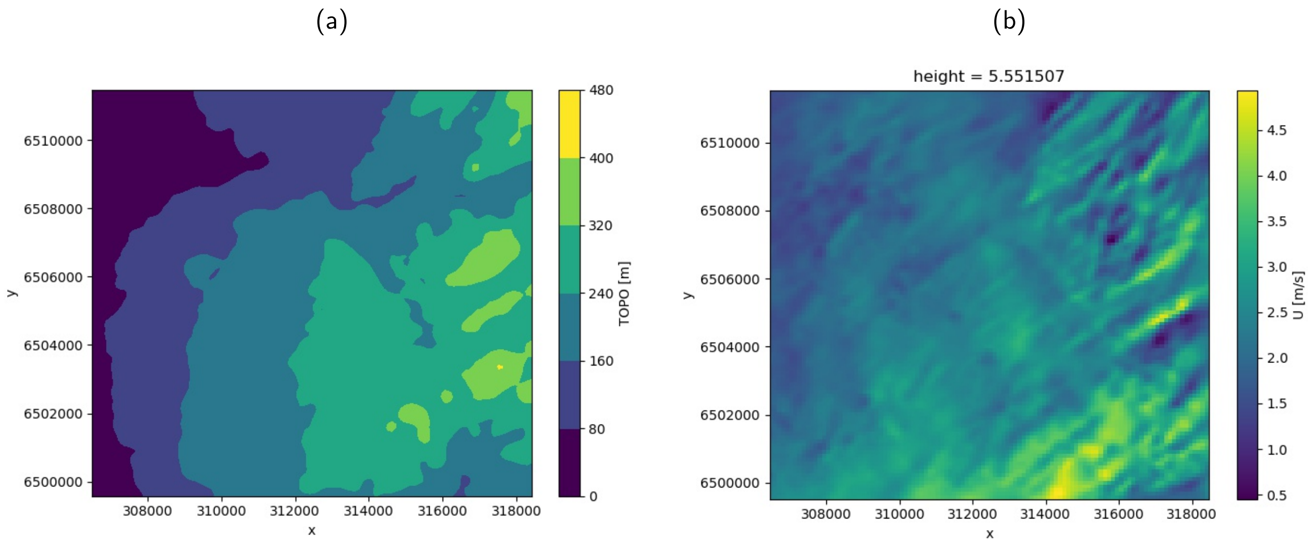

Figure 4: Visualization of data included in wrf_NW_2018-06-12_01_00.nc represented in UTM coordinates: (a) terrain elevation above mean sea level and (b) wind speed U at height of 5.6 m in ground-normal direction. x-axis: UTM Easting [m], y-axis: UTM Northing [m].

contains the variables listed in Tab. 5. The data are defined with respect to the Easting-Northing UTM coordinates (X,Y) at a height of 1.5 m above the ground. The grid dimensions are equal to $M_x = 201$ and $M_y = 201$ for all data files. The 1/3 octave-band Sound Pressure Level data are provided for the central frequencies in the SPL_xxxHz variables where xxx represents the frequency of interest.

A python script *read_sound_data.py* to read the acoustic output files is also provided in the database, giving an example of data plot, as shown in Fig. 5. The data contained in the netCDF file can also be easily loaded in visualization software like Paraview or Tecplot.

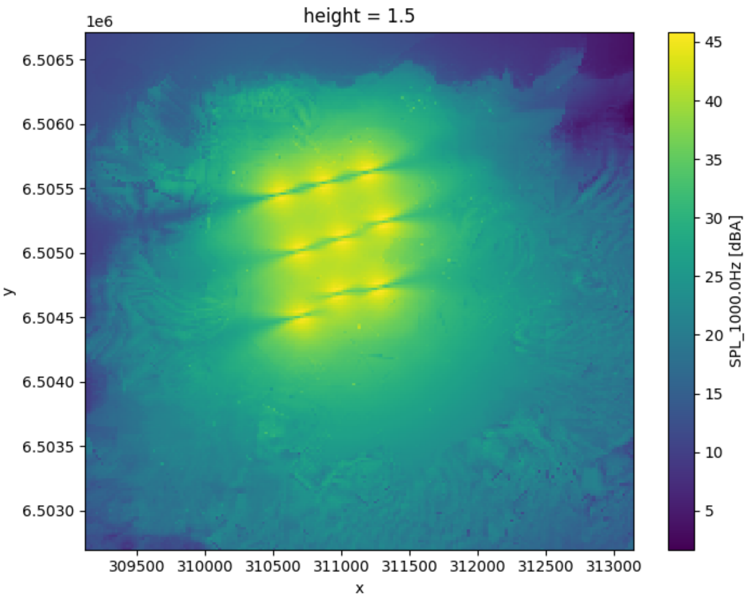

Figure 5: Visualization of 1/3 octave-band Sound Pressure Level at 1000 Hz included in Spp_ATM-NW_observer_grid.nc in UTM coordinates. x-axis: UTM Easting [m], y-axis: UTM Northing [m].

Index	Land description
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forests
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/natural vegetation mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Water
18	Wooded Tundra
19	Mixed Tundra
20	Barren Tundra

Table 4: Description of Summer-Winter averaged land use categories corresponding to variable LAND_USE in weather data input file.

Variable	Description	Dimension	Type	Unit
lon	Longitude coordinates	$M_y \times M_x$	float32	$^\circ$
lat	Latitude coordinates	$M_y \times M_x$	float32	$^\circ$
X	Easting UTM coordinates	$M_y \times M_x$	float64	m
Y	Northing UTM coordinates	$M_y \times M_x$	float64	m
Z	Height above the ground	$M_y \times N_x$	float64	m
SPL_xxxHz	1/3 octave band Sound Pressure Level at xxx Hz,			
	xxx to be replaced by the frequency	$M_y \times N_x$	float64	dBA
projected UTM zone	UTM zone	1	integer	-
projected UTM letter	UTM letter	1	letter	-

Table 5: Description of acoustic results stored in netCDF files.

References

[1] Høg-jaeren vindkraftverk. https:https://www.vindenergi.no/project/hog-jaeren-vindpark. Accessed: 2022-09-20.

[2] R. Amiet. Noise due to turbulent flow past a trailing edge. *Journal of Sound and Vibration*, 47(3): 387–393, aug 1976. ISSN 0022460X. doi: 10.1016/0022-460X(76)90948-2.

[3] J. Christophe, S. Buckingham, C. Schram, and S. Oerlemans. zEPHYR - large on shore wind turbine benchmark [dataset], zenodo, https://doi.org/10.5281/zenodo.6380879, Mar 2022.