Modelling wind flow in forested area: a parametric study

Stéphane Sanquer[1], Julien Berthaut-Gérentes[1] , Luis Cosculluela Soteras[2]

[1]Meteodyn
[2]Iberdrola Renovables

Abstract

This paper presents an analysis of CFD modelling, using a *k-L* turbulence model designed for forested areas. Meteodyn and Iberdrola Renovables have undertaken a systematic analysis of measurements data obtained in numerous sites, compared with Computation Fluid Dynamic approach. The analysis has consisted in highlighting the influence of several parameters on the shear defined as the vertical gradient of wind speed and the turbulence intensity at the wind turbine hub height. The influence is studied according to the forest description (density, height, shape of trees) and according to modelling parameters (Turbulent length scales, Dissipation parameter). Evaluation of the error ranges on wind shear and turbulence intensity is made according to the location of the wind turbines regarding the forest.

Introduction

Forested areas generate high level turbulence and strong wind shears which could be unfavorable to wind turbine siting. An accurate estimation of these parameters is thus crucial for the reliability of such wind farm projects. During the recent years, the CFD approach has proven its efficiency for wind resource assessment in complex terrains. However, the wind flow modelling in forested areas remains a topic where accuracy has still to be improved.

In Meteodyn WT [1], the canopy area is considered as a porous media where drag forces are applied, and where the turbulence length scales are modified. Turbulence is generated by the flow shear and dissipated according to these turbulence length scales. In two-equation turbulence models, the production and dissipation rates of turbulence are the variables solved in order to calculate the turbulence fluxes and to close the Navier-Stokes equations system (Sogachev and Pancherov [2], Li et al. [3]). Following, for example Yamada [4], Mellor and Yamada [5], or Katul et al. [6], we know that the advantage of using a *k-L* model, compared to two-equation turbulence models, especially for canopy modelling. Furthermore, the thermal stability can be easily considered via the parameterization of the turbulence length scale [7].

This paper presents an analysis of CFD modelling, using *k-L* turbulence model designed for forested areas [8]. Meteodyn and Iberdrola Renovables have undertaken a systematic analysis of measurements data obtained in numerous sites, and have compared with CFD computations.

Sensitivity analysis

The analysis consists in highlighting the influence of several parameters on the shear defined as the vertical gradient of wind speed V_{h1}/V_{h2} and the turbulence intensity at the wind turbine hub height I_{h1}. Later in this paper, the hub height h_1 equals 30 m or 70 m.

Two analysis have been conducted: one for the flow downstream the forest (20 m height i.e. roughness equal to 1 m) and the other one for the flow above the same forest (Figure 1). The country side roughness is equal to 0.05 m.

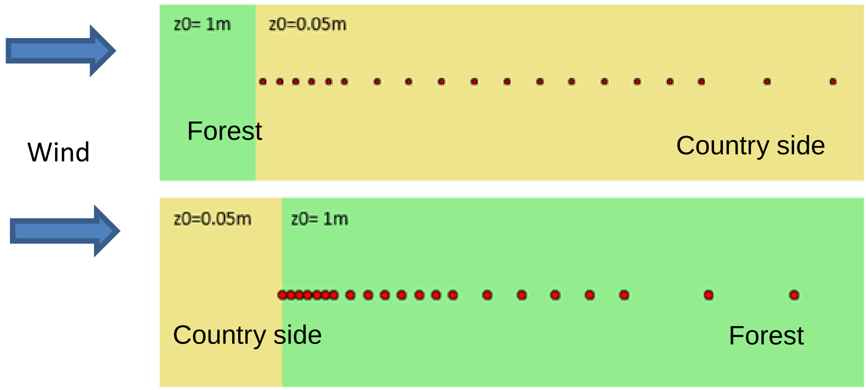

Figure 1: Configurations for the sensitivity analysis and locations of the vertical profiles

Three geometrical parameters are used to describe the forest:

- The height of the canopy (H_{canopy})
- The density of the forest (d)[1]
- The shape of the porous volume defined with the Leaf Area Density shape (LAD) as shown in figure 2 for various kind of trees.

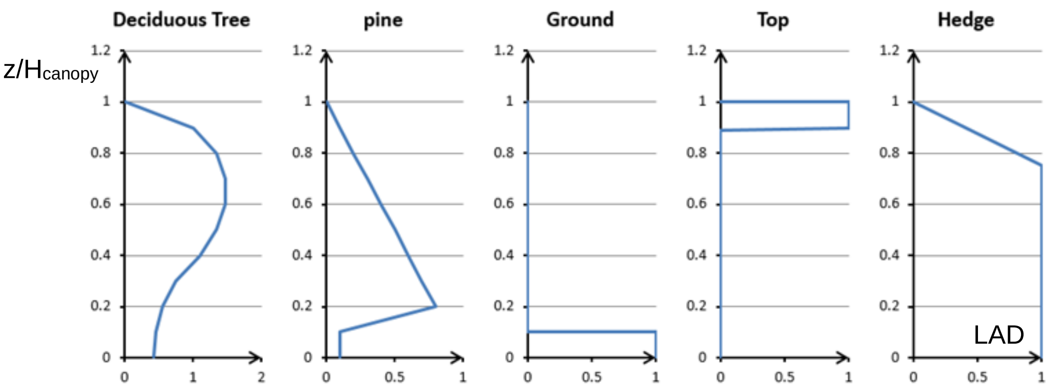

Figure 2: Leaf Area Density shape (LAD)

[1] Density depends on the volumic drag coefficient. Calibrations were carried out previously to define relationship between them

The turbulence model is parameterized according to:

- The thermal stability of the Atmospheric Boundary Layer, given by the turbulence length in the atmospheric boundary layer
- The turbulence length scale inside the forest close around it (noted “inside” and “vicinity” in Tables 1 and 2.
- The dissipation parameter of the turbulence model (C_{μ})

Figure 3a shows the wake effect of a forest, through the wind shear depending on the distance of the forest. The shear is affected by the forest density before distance lower than 50*H* (here the canopy height is *H* = 20 m). We see also in figure 3b the wind shear evolution, above the forest. In both cases, the shear is largely affected by the forest density.

Figures 4a and 4b shows the influence of the stability of the Atmospheric Boundary Layer respectively in the wake of the forest and above the forest. In both cases, the shear is largely affected everywhere by the stability both downstream and above the forest in contrast to the forest parameter (density, LAD, height)

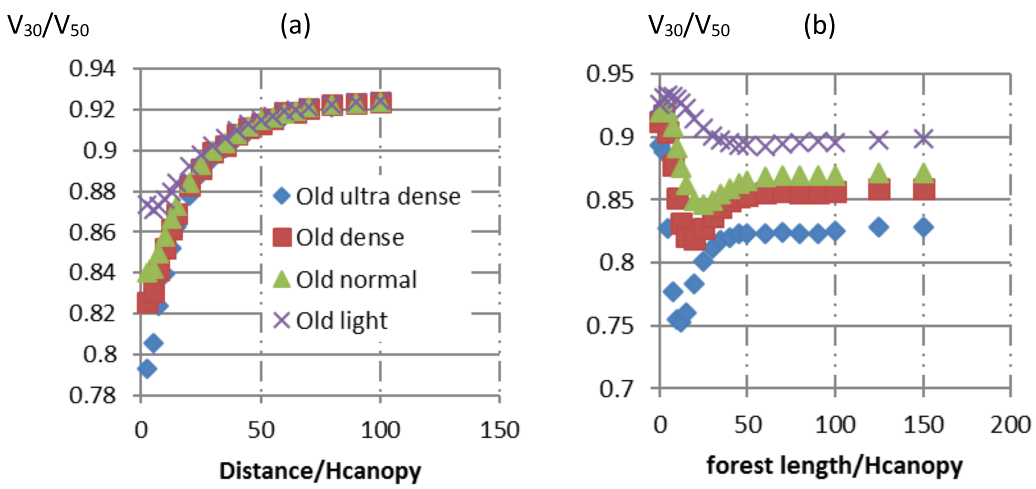

Figure 3: Ratio V30/V50 evolution downstream (a) and above (b) the forest Influence of forest density.

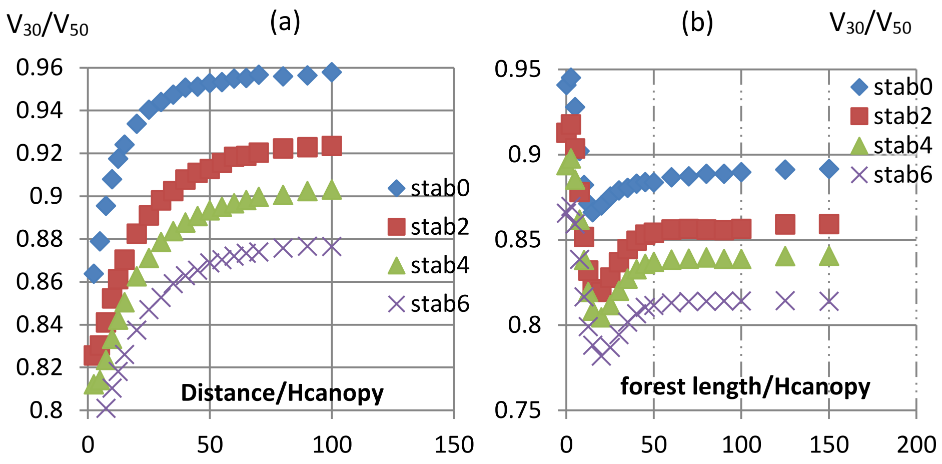

Figure 4: Ratio V30/V50 evolution downstream (a) and above (b) the forest
Influence of the atmospheric stability.
Stab 0 : unstable; Stab 2 : neutral; Stab 4 : slightly stable; Stab 6 : stable

The influence of each parameter (geometric and model) is given on tables 1 and 2, the influence of each parameter (geometric and model) on the velocity ratio V_{50}/V_{30} and on the turbulence intensity range I_{30} are shown in Tables 1 and 2.

Forest density seems to be the most important parameter to achieve precision both on shear and turbulence intensity. Canopy height is also important and should be estimated easier than the density. Shear depends slightly on LAD and on the turbulence model *(L_T, C_μ)*.

	Downwind distance < 50 H		**Downwind distance > 50 H**	
	Influence on V_{50}/V_{30}	*Influence on TI_{30}.*	*Influence on V_{50}/V_{30}*	*Influence on TI_{30}.*
LAD	< 0.02	0.03–0.06	< 0.02	< 0.03
Forest density	0.04-0.06	0.075	< 0.02	< 0.03
Canopy height	0.02–0.04	0.03–0.06	< 0.02	< 0.03
Turbulence length (inside)	0.02–0.04	0.03–0.06	< 0.02	< 0.03
Turbulence length (vicinity)	< 0.02	< 0.03	< 0.02	< 0.03
Turbulence length (ABL)	0.04-0.06	> 0.10	0.04-0.06	> 0.10
Dissipation parameter C_μ	< 0.02	0.06–0.09	< 0.02	0.03–0.06

Table 1: Dependence of Shear and Turbulence on forestry parameters - downstream the forest

	Fetch < 50 H		Fetch > 50 H	
	Influence on V_{50}/V_{30}	*Influence on TI_{30}*	*Influence on V_{50}/V_{30}*	*Influence on TI_{30}*
LAD	0.02–0.04	0.03–0.06	< 0.02	< 0.03
Forest density	> 0.06	> 0.10	>0.06	> 0.10
Canopy height	0.02–0.04	0.03–0.06	< 0.02	< 0.03
Turbulence length (inside)	0.02–0.04	0.03–0.06	< 0.02	0.03–0.06
Turbulence length (vicinity)	< 0.02	< 0.03	< 0.02	< 0.03
Turbulence length (ABL)	0.04-0.06	0.06-0.09	0.04-0.06	> 0.10
Dissipation parameter C_μ	< 0.02	< 0.03	< 0.02	< 0.03

Table 2: Dependence of Shear and Turbulence on forestry parameters - above the forest

Case study

In order to improve the knowledge about wind modelling in forestry areas, a great number of data have been gathered by Scottish Power Renewables, a company of Iberdrola Renovables for a couple of sites in Scotland. These sites have been chosen both for their forested environment, the good quality of data, a moderate orography and an accurate description of the forest environment.

The data treatment was conducted at each met mast with the following criteria:

- Likely neutral conditions: no snow, time between sunrise to sunset, and wind speed greater than 8m/s.
- The wind rose was binned by 30 deg wide sectors and only sectors representing more than 6% of the whole data set were kept
- In each sector, shear (i.e. windspeed ratio) and turbulence intensity at the top of the mast were computed.

Comparisons between these data and numerical results were made for each wind sectors for shear defined as the ratio between wind speed at several heights to wind speed at hub height.

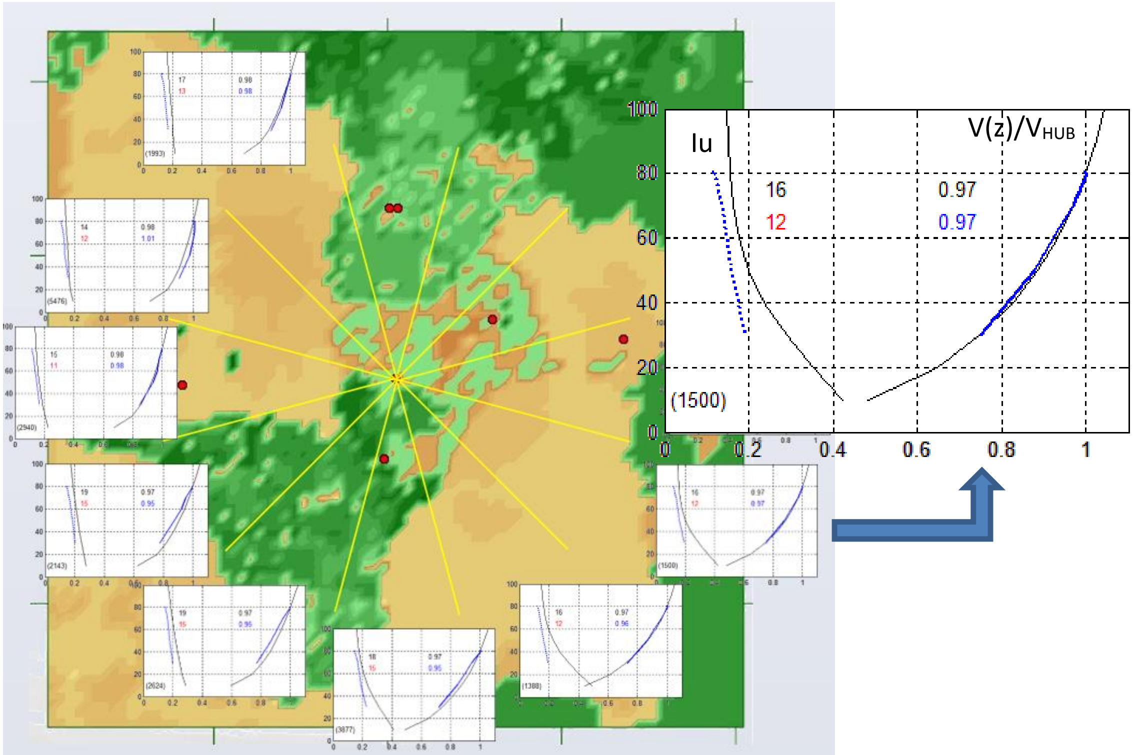

Figure 5: comparison terrain measurements (blue) vs numerical model (black line) for every wind sectors

In the computation, the forests characteristics are described using 3 parameters: trees height, foliage distribution, forest density. Thermal stability is considered as neutral condition.

Figure 6 shows the comparison between the numerical model and the measurements in the wake of the forests. The density of the forest is defined as high. Discrepancies are concentrated in the near wake. In this region and for most of the cases, the numerical model underestimates the wind shear created by the forest. In order to reduce discrepancies of the shear downstream the forest, a calibration of the density was carried out by considering each wind sector.

The errors distributions are shown at figure 7, firstly with one density value (left side) and after calibrating the forest density mapping (right side). 80% of the comparisons give error considered as weak (absolute difference inferior to 0.02 on V_{50}/V_{30} compared to 70% before calibration.

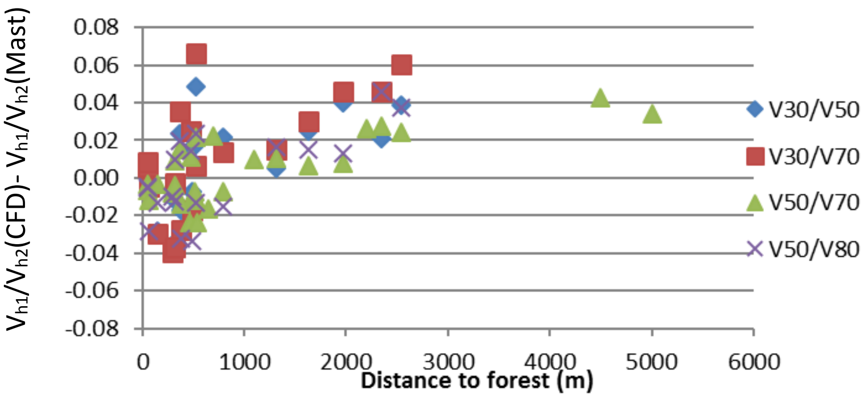

Figure 6: comparison terrain measurements vs numerical model for every wind sectors

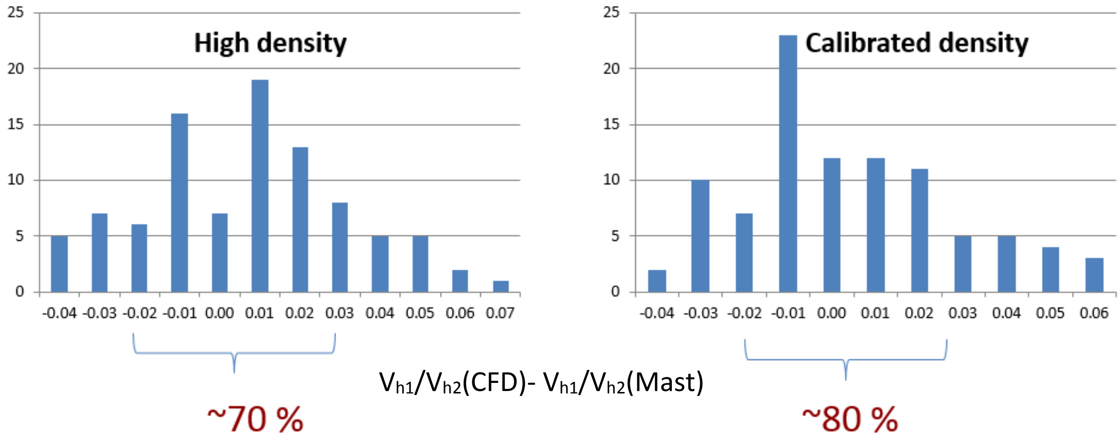

Figure7: Distribution of shear errors

Conclusion

The conclusions of the study are the followings:

- Shear discrepancies stay in the range [-0.02; +0.02] for 80 % of the SPR data base
- Forest density seems to be the parameter that has both a great influence and a large imprecision. Canopy height is estimated easier than density.
- Users should calibrate firstly the density of the forest because shear depends slightly on the turbulence model (L_T, C_μ) and on LAD.
- Shear is highly dependent on the stability, so what is the stability above forest? Does the forest change the stability of the Atmospheric boundary layer?

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