Modelling wind flow in forested area: a parametric study

Stéphane SANQUER [(1)], Julien Berthaut-Gerentes [(1)] , Luis Cosculluela Soteras [(2)]

(1) Meteodyn
(2) Iberdrola Renovables

Introduction

Forested areas are increasingly of interest regarding wind farms development. Nevertheless, the trees perturbations on the flow generate high level turbulence and strong wind shears which could be unfavorable to wind turbine sitting. 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 can still be improved.

It's admitted that only the mechanical effects should be considered inside the canopy i.e. it is not necessary to include the thermal effects into the forest. The description of the geometric parameters and the turbulence modelling seems to be essential to achieve a good description of the wind flow around the forest. The canopy area is defined as a porous media where the wind flow is slowed down. The forest model is a combination of a drag forces model depending of the forest porosity and a turbulence viscosity model. Turbulence is generated by the flow shear and dissipated since the most energetic vortices are split themselves in smaller vortices up to the dissipation. In classical two equation models (k-eps, k-Omega…), 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. This could be very complex to solve in forest canopy, notably because sets of constant have to be defined for instance among others by Sogachev and Pancherov ([1]) or Li *et al.*. ([2]. Yamada (1982, [3]) was one of the first to use a k-L model where L is a mixing length introduced by Mellor and Yamada (1974, [4]) to assess the turbulence in plant canopies. Katul et al. ([5], 2004) concluded that there is no clear advantage to including a turbulent kinetic dissipation rate budget when mixing length can be specified instead. Furthermore, thermal exchanges between land cover may change the atmospheric boundary layer behaviors such as the shear and the turbulence, upstream, above and downstream the forested area. In that context, the thermal stability should be considered in the modelling and the mixing length can be specified in such area (Yamada et Arritt [6]).

The paper focus on efforts on improving the one equation model (k-L) for the forested area. Meteodyn and Iberdrola Renovables have undertaken a systematic analysis of measurements data obtained in numerous sites, and have compared with CFD computations using the commercial CFD software Meteodyn WT. The turbulence model was introduced in a previous paper (Jiang et al. [7])

The three last steps are presented in this paper:

- Sensitivity analysis to highlight the influence of geometric and model parameters
- Case study: measurement analysis and comparisons against numerical simulations
- Conclusions: strategy to compute the wind in forest terrains

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 Ti(h1). Later in this paper, the hub height h1 equals 30 m or 70 m.

Two scenarios were used: Downstream the forest (Top) and above the forest (Bottom) as presented below. The position of the vertical profiles for the data extraction are respectively given from the end of the forest or the beginning of the forest.

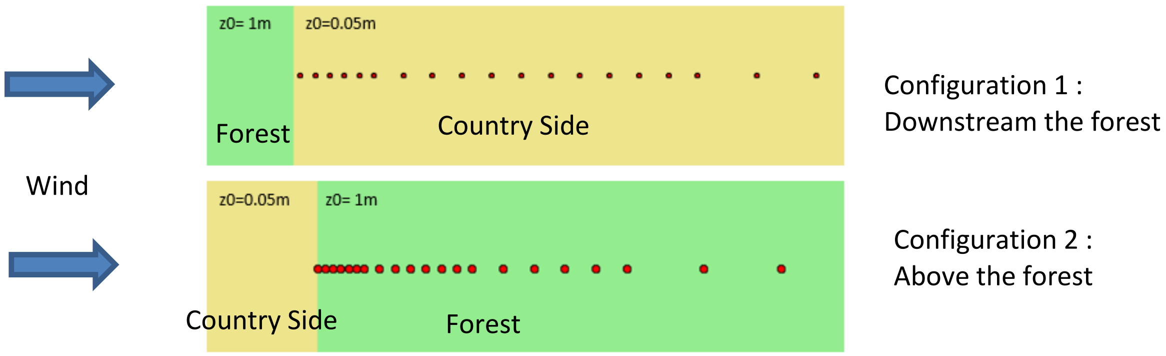

Figure 1: configurations of the sensitivity analysis and positions of the vertical profiles

Three geometrical parameters were used to describe the forest:

- The height of the canopy (H)
- The density of the forest (d)
- The shape of the porous volume defined with the Leaf Area Density shape (LAD, figure 2))

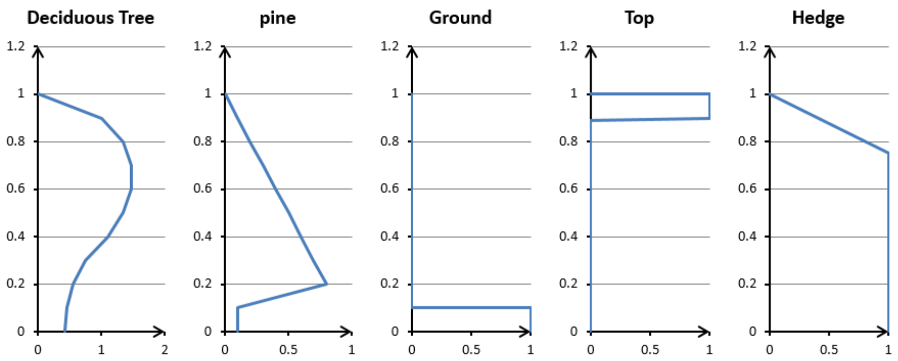

Figure 2: Leaf Area Density shape (LAD)

Three parameters are used to describe the turbulence model:

- The stability of the Atmospheric Boundary Layer
- The turbulence length into the forest and close around the forest (Lt)
- The dissipation parameter of the turbulence model (Cµ)

Figure 3 (left side) 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=20m). Figure 3 (right side) shows effect above the forest, through the wind shear depending on the distance of the forest edge. The shear is affected by the forest density everywhere.

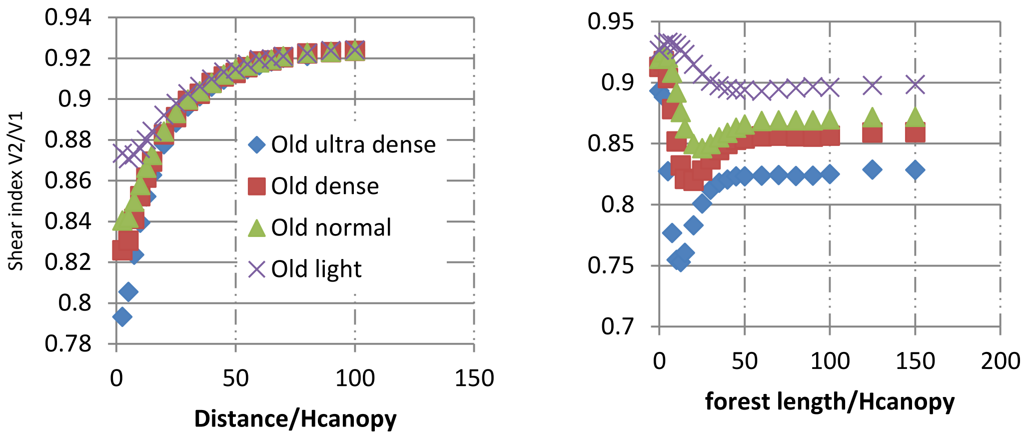

Figure 3: V(30m)/V(50m): Downstream the forest (Left), Above the forest (right).

The influence of each parameter (geometric and model) is given on tables 1 and 2 according to 4 ranking classes of the velocity gradient range α=V(h1)/V(h2) and of the turbulence intensity range (Ti(h1)). Ranking classes are also detailed in the tables 1 and 2.

The tables bellow summarizes the results.

Downstream	<50h		>50h	
LAD	α(~)	TI(+)	α(~)	TI(~)
Density	α(++)	TI(+++)	α(~)	TI(~)
Canopy height	α(+)	TI(+)	α(~)	TI(~)
Turbulence length in the forest	α(+)	TI(+)	α(~)	TI(~)
Turbulence length above the forest	α(~)	TI(~)	α(~)	TI(~)
Stablility Lt	α(++)	TI(+++)	α(++)	TI(+++)
Dissipation parameter Cμ	α(~)	TI(++)	α(~)	TI(+)

	Δα	ΔTi
~	<0.02	<3%
+	0.02-0.04	3% - 6%
++	0.04-0.06	6% - 9%
+++	>0.06	>10%

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

Above the forest	<50h		>50h	
LAD	α(+)	TI(+)	α(~)	TI(~)
Density	α(+++)	TI(+++)	α(+++)	TI(+++)
Canopy height	α(+)	TI(+)	α(~)	TI(~)
Turbulence length in the forest	α((+)	TI(+)	α(~)	TI(+)
Turbulence length above the forest	α(~)	TI(~)	α(~)	TI(~)
Stablility Lt	α(++)	TI(++)	α(++)	TI(+++)
Dissipation parameter Cμ	α(~)	TI(~)	α(~)	TI(~)

	Δα	ΔTi
~	<0.02	<3%
+	0.02-0.04	3% - 6%
++	0.04-0.06	6% - 9%
+++	>0.06	>10%

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

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 (Lt, Cμ).

Case study

In order to improve the knowledge about wind modelling in forestry area, 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:

- Selection of time-steps for an assumed neutral condition:
  - Positive temperature to avoid snow at the nearest met station
  - Time between sunrise to sunset to avoid night
  - Only high speed winds were kept (> 8m/s)
- The wind rose was binned by sectors (30°) and only representative sectors were kept (more than >6% of the whole data set)
- In each sector, shear (slope 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.

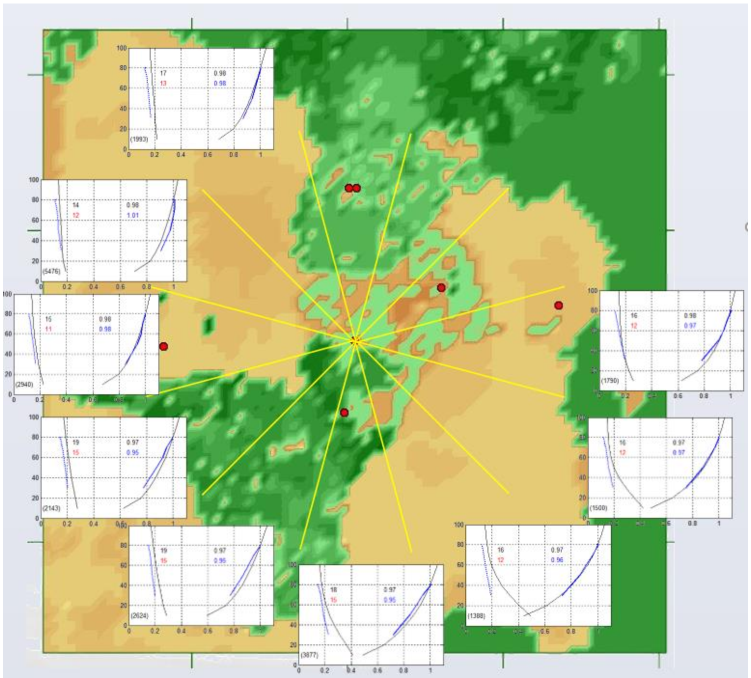

Figure 3: comparison terrain measurements vs numerical model for every wind sectors

For the computation the forests characteristics are described using physical parameters:

- The height of the trees
- The foliage distribution
- The forest density

All the computations were made with a stability parameter corresponding to a neutral condition. The density of the forest was defined as high for all the forest as the type of trees is pins. Figure 4 shows the discrepancies between the numerical model and the measurements in the wake of the forests. 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 sectors. Distribution of errors are shown on figure 5 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 ($-0.02<\Delta\alpha<0.02$) compared to 70% obtained before calibration.

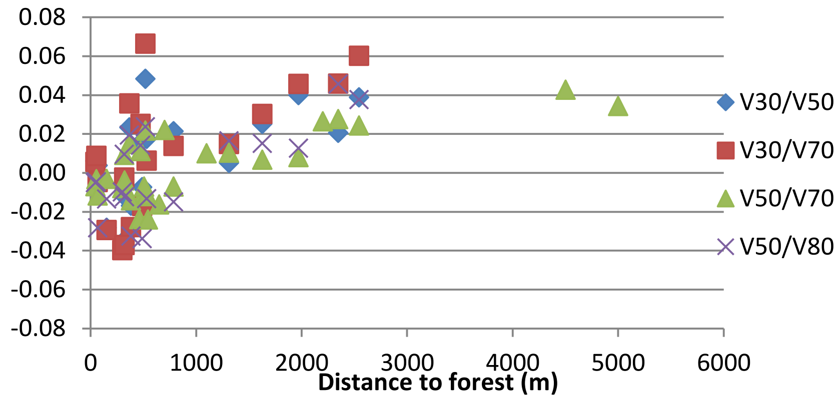

Figure 4: comparison terrain measurements vs numerical model for every wind sectors

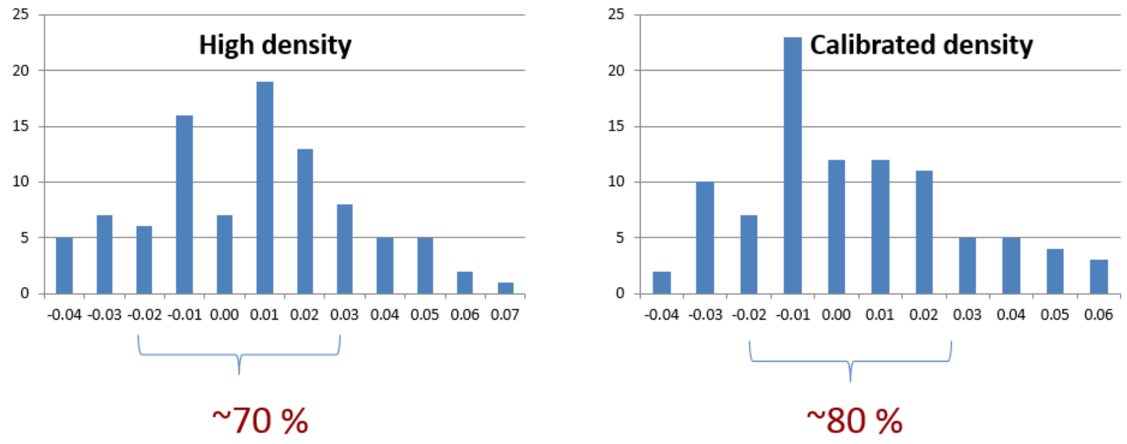

Figure 5: Distribution of shear errors

Conclusions

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 (Lt, Cμ) and on LAD.
- Shear is highly dependent on the stability, so what 's the stability above forest? Does the forest change the stability of the Atmospheric boundary layer?

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