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IBERDROLA RENOVABLES

Modelling wind flow in forested area: a parametric study

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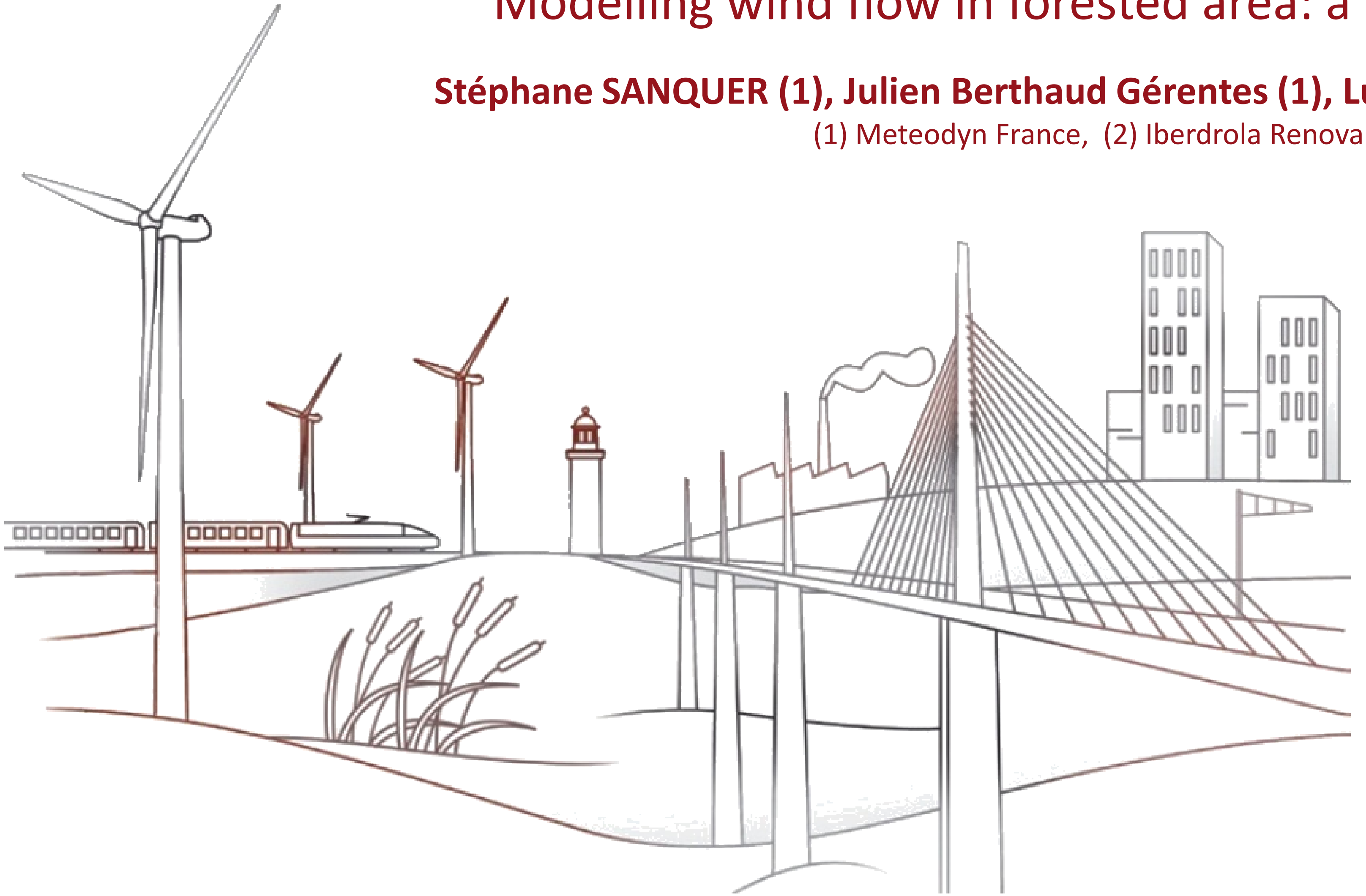


Context…

Forests generate high level turbulence and strong wind shear

$\Rightarrow$ CFD approach may be an alternative to wind resource assessment

$\Rightarrow$ Accuracy has still to be improved in such complex situation

Question : What's the best RANS approach to assess the wind around canopy ?

Katul et al. (2003), Boundary Layer Meteorology

"No clear advantage to including a turbulent kinetic dissipation rate budget when mixing length can be specified instead"

$\Rightarrow$ Focus efforts on improving one equation model (k-L) for the forest

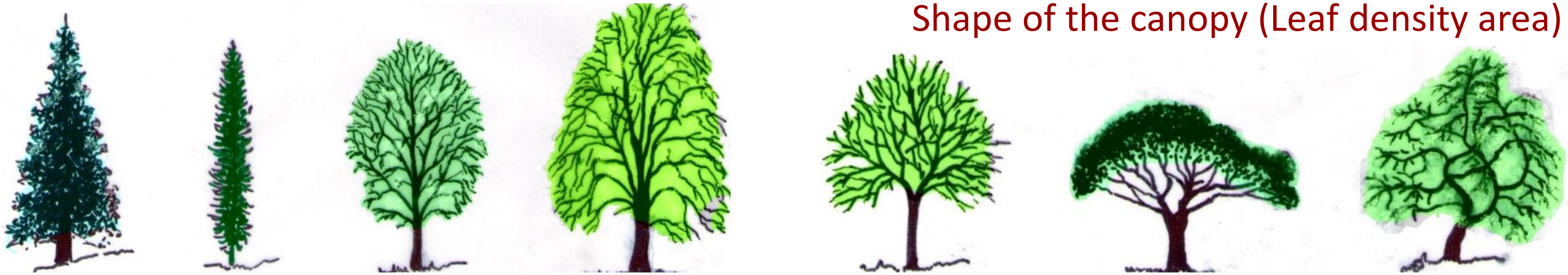
$\Rightarrow$ Consideration of the thermal stability via the parametrization of the turbulence length scale

Above the forest

Downstream the forest

Roughness, Upstream turbulence, Stability ?

Shape of the canopy (Leaf density area)



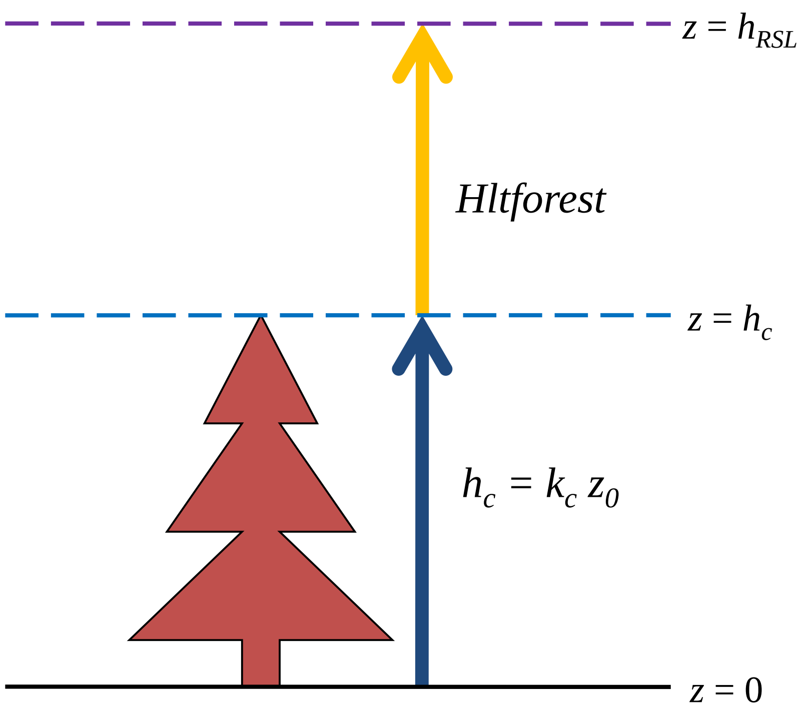
…and purposes

Highlighting the influence of several parameters describing the forest (density, canopy shape) or the turbulence or the ABL stability
=> Ranking the parameters influence

Analysis will be carried out on shear and turbulence behaviors above the forest and downstream of the forest ?

Comparisons “Full scale measurements vs CFD”
=> Scottish wind parks from Iberdrola Renovables

The forest model => Modelling the drag forces and turbulence viscosity



$$h_c = k_c z_0 \qquad h_{RSL} = Hltforest + h_c$$

h_c : canopy height
z_0 : ground roughness
h_{RSL} : sub-layer height

$$\frac{1}{l} = \begin{cases} \frac{1}{l_0} + \frac{1}{l_f}, z \le h_c \\ (1-\alpha)(\frac{1}{l_0} + \frac{1}{l_f}) + \alpha(\frac{1}{l_0} + \frac{1}{\kappa z}), h_c < z < h_{RSL} \\ \frac{1}{l_0} + \frac{1}{\kappa z}, z \ge h_{RSL} \end{cases}$$

$$\alpha = \frac{z - h_c}{h_{RSL} - h_c}$$

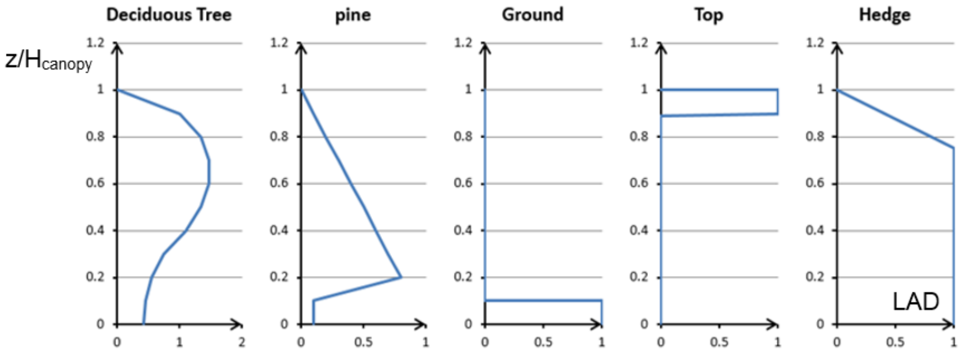
Height of the first cell < z < h_c :

$F_i = -\rho C_{dv} |\overline{u}_i| \overline{u}_i$ Drag force ∝ forest density

Parameters

Three geometrical parameters to describe the <u>forest:</u>

- Height of the canopy
- Density of the forest
- Shape of the porous volume (Leaf Area Density shape)

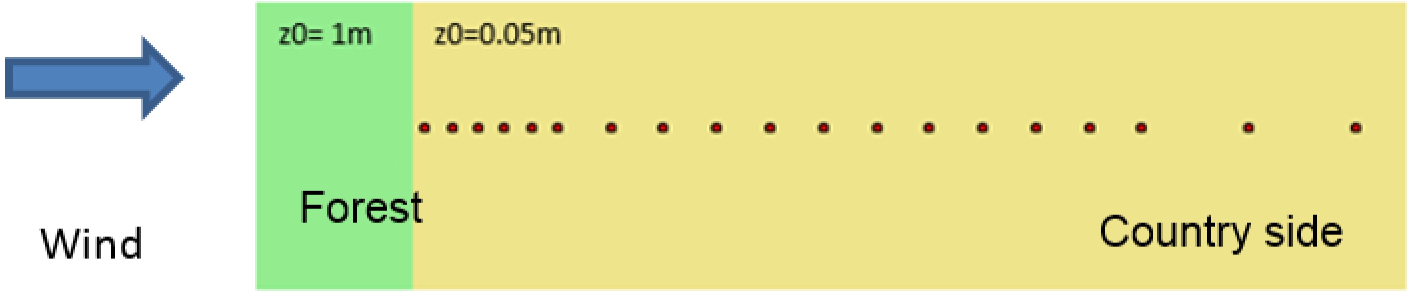


Three parameters to describe the <u>turbulence model:</u>

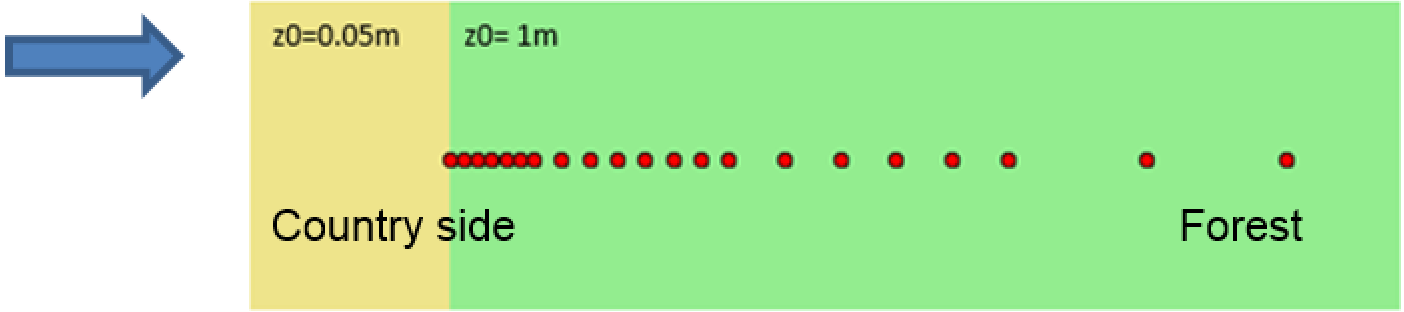
- Stability of the ABL
- Turbulence length close to the forest (Lt)
- Dissipation of the turbulence (Cμ)

$$\frac{1}{l} = \begin{cases} \frac{1}{l_0} + \frac{1}{l_f}, z \leq h_c \\ (1-\alpha)(\frac{1}{l_0} + \frac{1}{l_f}) + \alpha(\frac{1}{l_0} + \frac{1}{\kappa z}), h_c < z < h_{RSL} \\ \frac{1}{l_0} + \frac{1}{\kappa z}, z \geq h_{RSL} \end{cases}$$

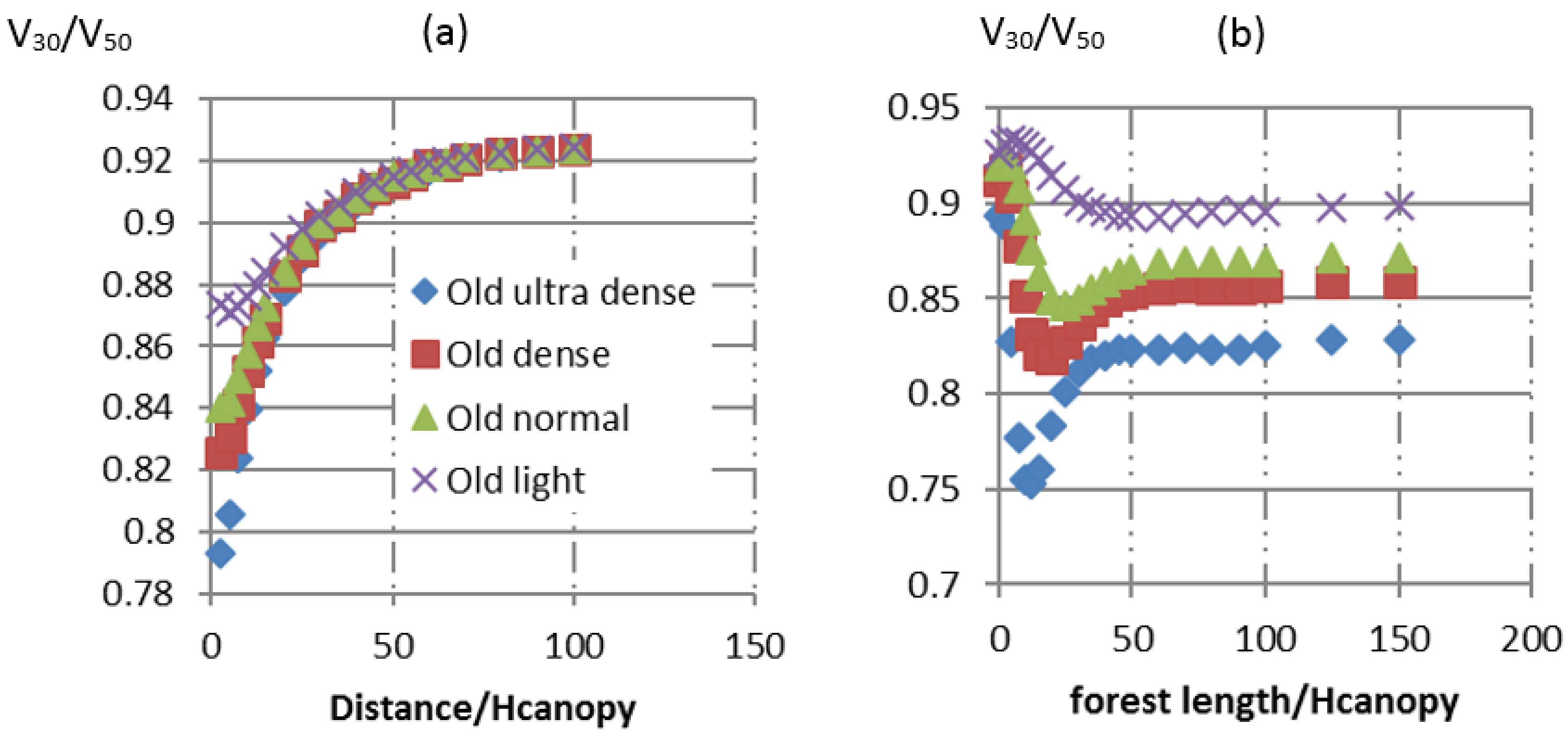
Above or downstream the forest



Wind



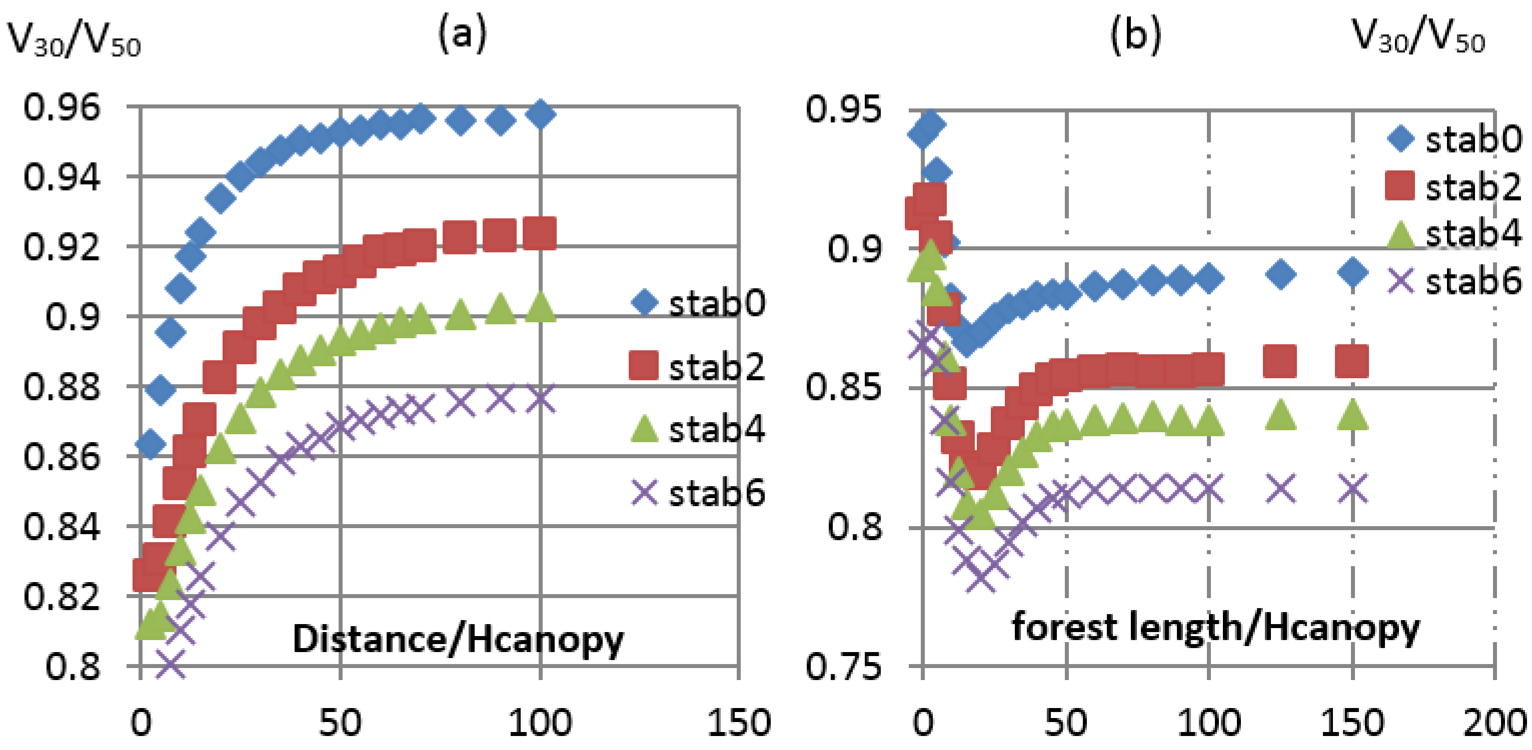
Influence of the forest density on the shear



Downstream the forest

Above the forest

Influence of the ABL stability



Downstream the forest

Above the forest

Downstream the forest

	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

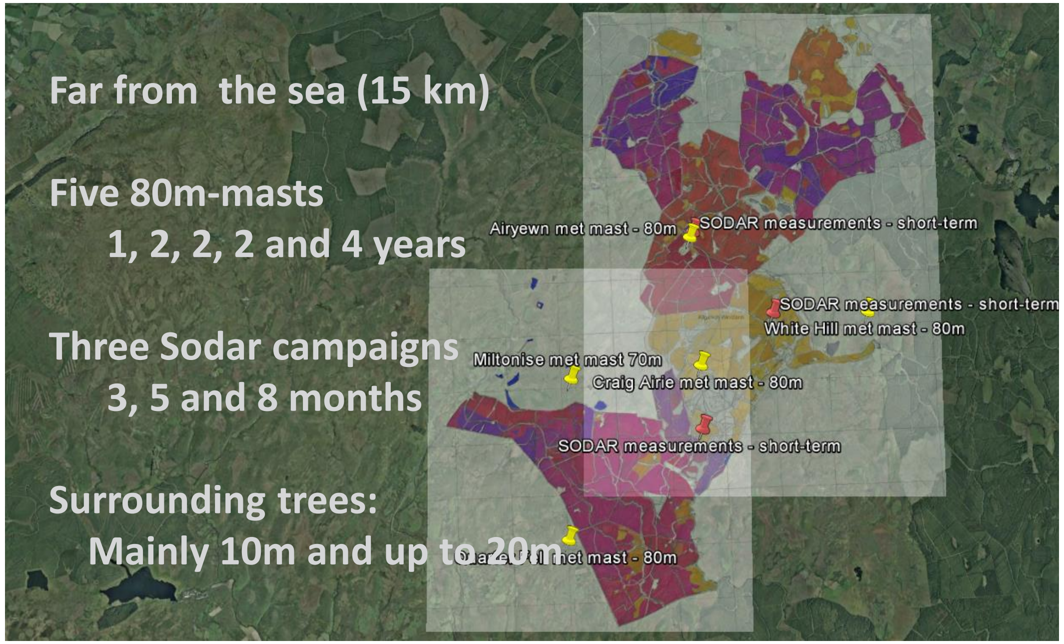
Table 1: Dependence of Shear and Turbulence on forestry parameters - downstream the forest

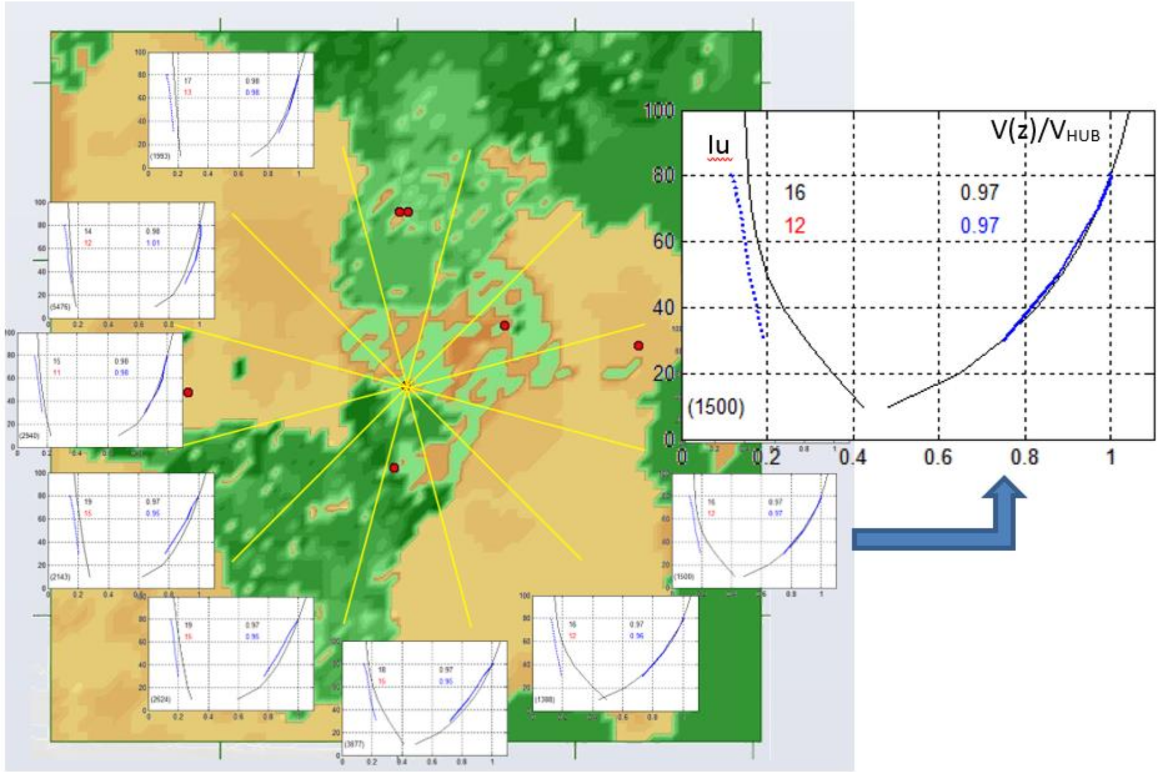
Above the forest

	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 : Full scale measurements vs CFD

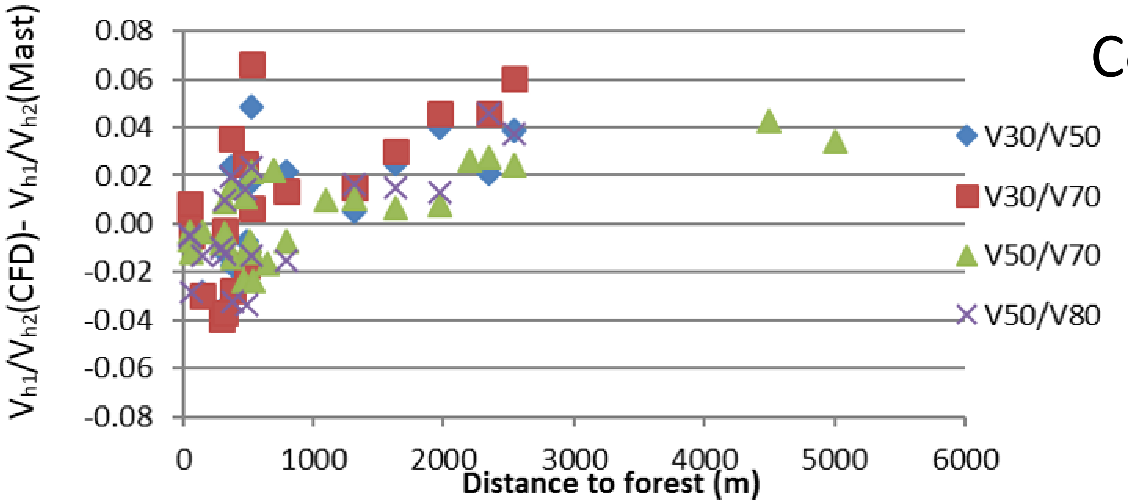




Data treatment

At each met mast :

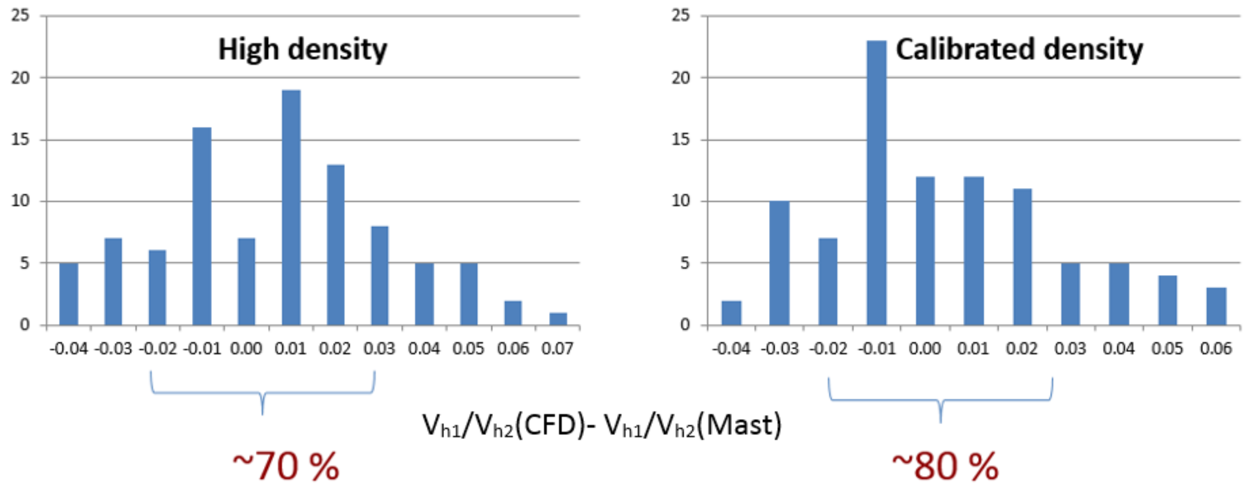
- ➢Selection of time with Data OK and neutral conditions
  - Met station=> positive temperature (to avoid snow)
  - Time between sunrise +3H sunset-1H (to avoid night)
  - High wind speed (vertical average > 8m/s)
- ➢Bin by sector (30°); keep only representative sectors (>6%)
- ➢In each sector, compute shear (slope ratio) and turbulence intensity at the top of the mast.



Comparisons between the numerical models and the measurements in the wake of the forest

Distribution of shear errors

Weak errors (negligeable) if $\Delta<0.02$



The conclusions of the study are the followings:

- Shear discrepancies stay in the range [-0.02; +0.02] for 80 % of the Scottish Power Renewables 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?