CFD simulations of the Egmond aan Zee wind farm using high resolution mesoscale predictions

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Abstract

Due to the complexity and uncertainty involved in the process of making power from wind, more and more advanced tools are being developed to maintain the sustainability and the growing trend of the wind industry. Prior to the development of a wind farm project, measured data are provided by limited installed wind masts at the site under investigation and by other nearby weather stations. Therefore, the wind resource assessment depends on the uncertainties and limitations of those measurements. To improve the reliability and limit the risks, weather prediction forecasting models can be employed in parallel with measurements, to investigate the local wind map and the potential wind power. Nevertheless, the physics involved at the inter-turbine or smaller scales cannot be captured by mesoscale modelling. To obtain predictions of such scales, high resolution mesoscale models are coupled with micro-scale computational fluid dynamics (CFD) simulations.

Results of neutral atmospheric stability over a defined wind sector have been averaged in time and extracted from mesoscale simulations using the Weather Research and Forecasting model (WRF) [1] with a very fine resolution (150 m). Those results were used to provide the inlet conditions of the micro-scale CFD simulations which were performed using the open-source CFD software OpenFOAM [2]. The predicted time-averaged atmospheric flow within the Egmond aan Zee wind farm is compared for both numerical approaches. The wind farm's total power estimations are compared to operational SCADA data.

Computational domain and boundary conditions

The computational mesh was generated with `blockMesh` and `snappyHexMesh`. The final grid size was 15Mi cells. An inlet velocity profile has been derived for the Atmospheric Boundary Layer (ABL) using high-resolution mesoscale modelling and the governing equations [Table 3]. Under the assumption of a homogeneous atmospheric flow and of local equilibrium between the production k and dissipation ε of turbulence, Eq. 1, 2 and 3 can be used [3]. For the ABL parametrization [Table 2], a plane at a distance of 25D ($D = 90$ m) upstream has been extracted from the mesoscale model, using a time-window of 5hr in which an average wind speed of 9.37 m/s and wind direction of $50°$ ($\pm 5°$) was observed. The velocities have been averaged over the plane and over available mesoscale heights in the range of $0 - 1$ km height. An average turbulence intensity (TI) of 8.943% has been extracted over the hub height and used to estimate the turbulence kinetic energy production from Eq. 4. The u_* is calculated by using Eq. 2 and 4. Then Eq. 5 is used to estimate a consistent z_0.

Table 1: Boundary conditions

	Dirichlet Fixed value	von Neumann Zero gradient
Inlet	$U_{Eq.1}, k_{Eq.2}, \varepsilon_{Eq.3}$	p
Top	$U_{Eq.1}, k_{Eq.2}, \varepsilon_{Eq.3}$	p
Outlet	p	U, k, ε
Bottom	ABL wall function	
Sides	symmetry conditions	
WT	actuator disk model	

Table 2: ABL initial conditions

U_{ref}	9.37 m/s
z_{ref}	65 m
k	1.0432 m^2/s^2
ε	0.003114 m^2/s^3
z_0	0.009558 m

Table 3: Governing equations

$u = \frac{u_*}{\kappa} \ln\left(\frac{z + z_0}{z_0}\right)$	(Eq. 1)
$k = \frac{u_*^2}{\sqrt{C_\mu}}$	(Eq. 2)
$\varepsilon = \frac{u_*^3}{\kappa(z + z_0)}$	(Eq. 3)
$k = \frac{3}{2}(\bar{U} TI)^2$	(Eq. 4)
$u_* = \frac{\kappa U_{ref}}{\ln\left(\frac{z_{ref} + z_0}{z_0}\right)}$	(Eq. 5)

Table 4: Modified k-ε turbulence model coefficients (Ref. [4])

C_μ	$C_{\varepsilon 1}$	$C_{\varepsilon 2}$	σ_k	σ_ε	κ
0.033	1.44	1.92	1.0	1.3	0.41

Figure 1: Dimensions of the computational domain and wind farm layout

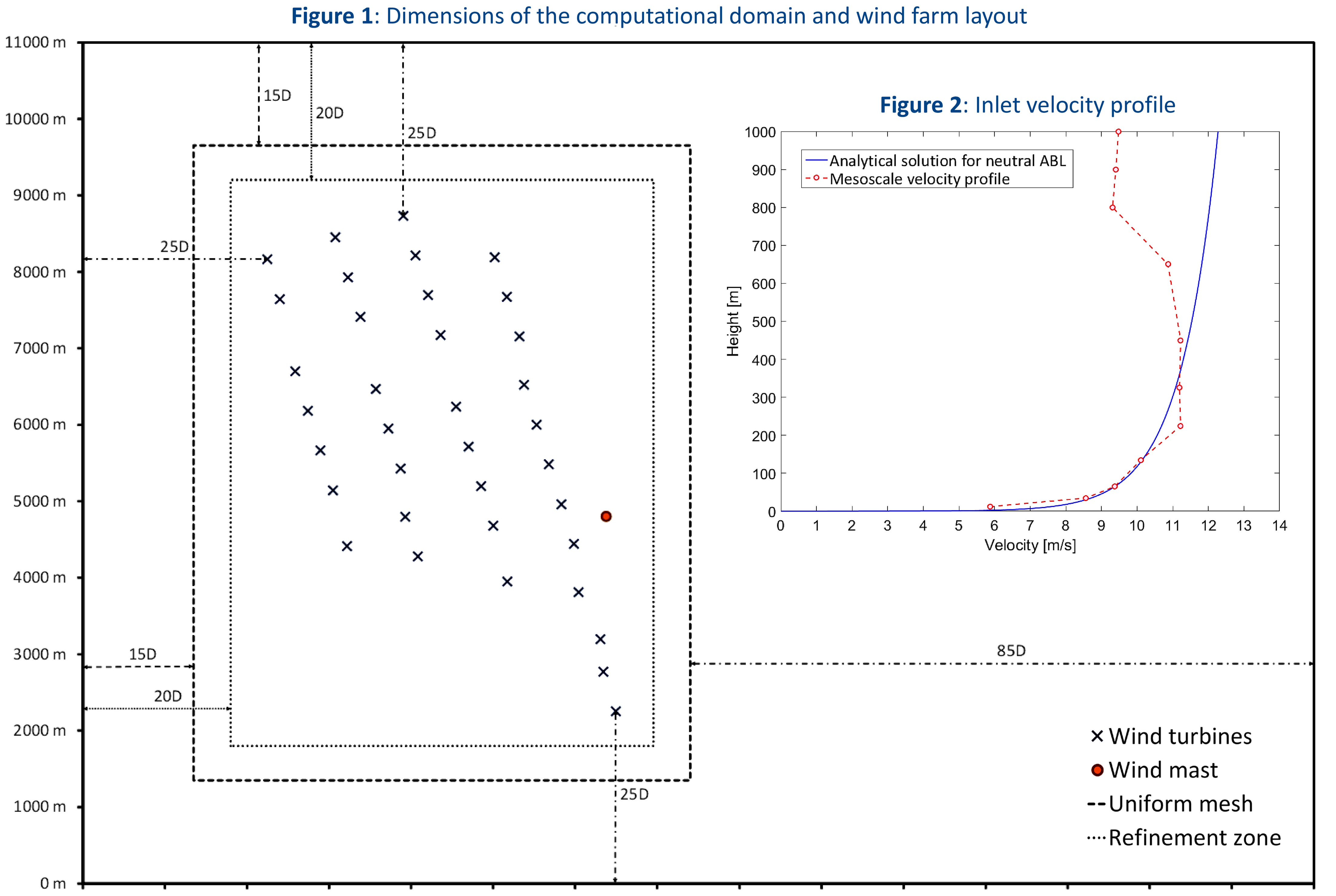

Figure 2: Inlet velocity profile

CFD simulations of Egmond aan Zee

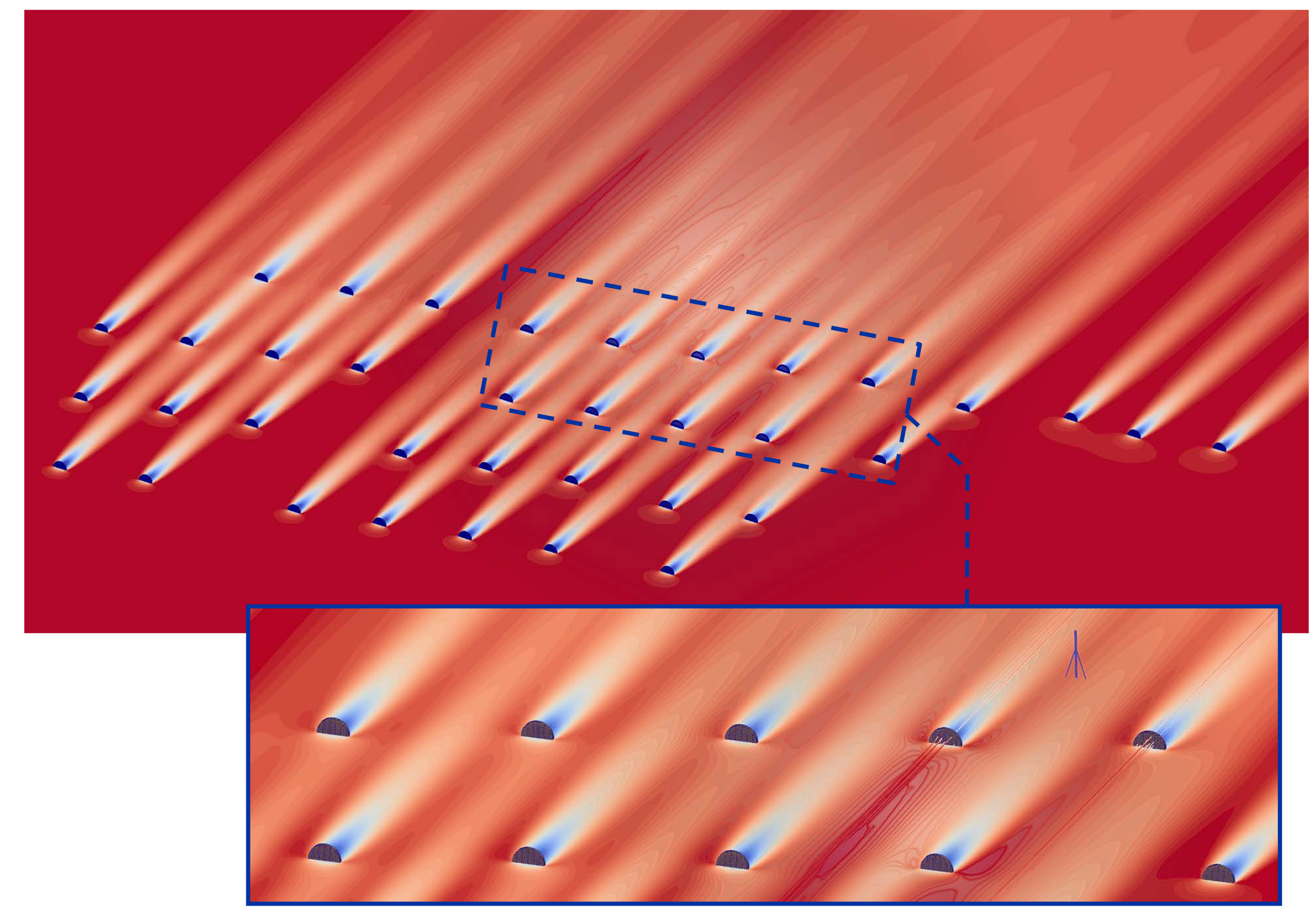

Figure 3: Velocity contours over the hub height. (Top: Wind farm layout. Bottom: Zoomed area and wind mast location)

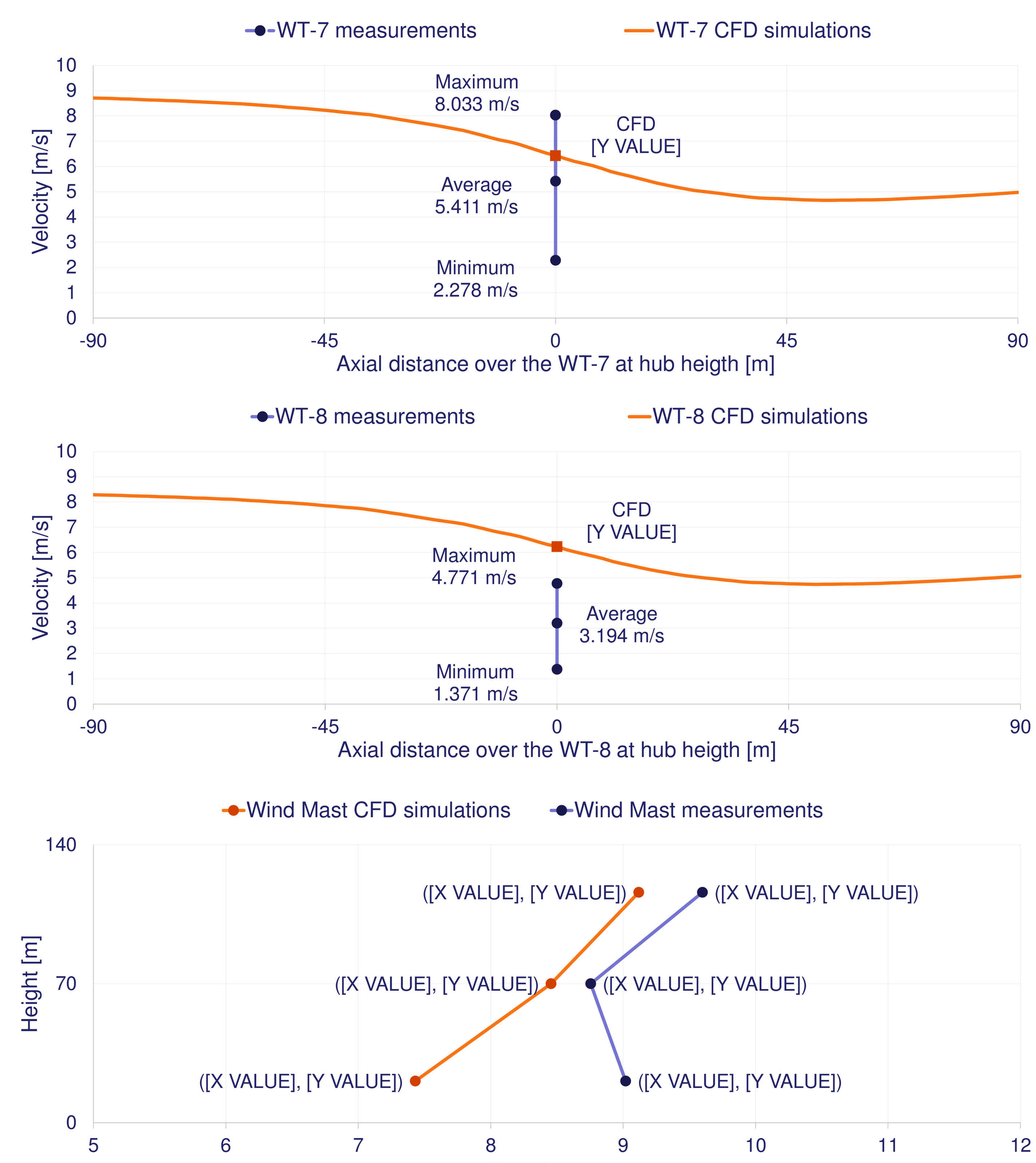

Figure 4: CFD simulations against SCADA data and wind mast measurements

Conclusions

A qualitative comparison of measured and modelled wind speeds has been done. Preliminary results over the selected wind sector, suggest that wind turbine 7 and 8, as well as the wind mast are within multiple wake effects from the upstream wind turbines. A further analysis of the available SCADA data is needed to ensure that the initial CFD values that were calculated from the mesoscale simulations are in accordance with the measured values within this time-frame.

CFD results from previous studies using the actuator disk model, show that the single wake expansion is very sensitive to the choice of turbulence model [4, 5]. The impact of using the k-ε turbulence model in multiple wake effects should be accounted.

References

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