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# Wind resource assessment over a complex terrain covered by forest using CFD simulations of neutral Atmospheric Boundary Layer with OpenFOAM and MeteoDyn

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## Abstract

Following the growth of wind sector and the scarcity of available land, the market share of onshore wind energy installation on complex terrain is expected to increase. Wind resource assessment is a crucial process for the successful development of a wind farm project. To estimate the future energy production on a specific site, developers investigate the potential wind power which is related to the local winds. For cases of complex terrain with significant changes in roughness due to vegetation or buildings, local winds can vary considerably across a wind farm site, resulting in inaccurate energy estimation.

The site under investigation is on an island of complex terrain covered by 70% of thick forest and trees of roughly 15 to 20 m height. The atmospheric boundary layer stability is mainly neutral with a very unidirectional wind direction from ESE. Two meteorological masts have been installed providing measurements of more than a year. Average wind speeds over the NW direction and at 78 m height were measured to be 2.698 m/s for the first met mast and 2.545 m/s for the second met mast respectively. A wind resource assessment has been performed using 12 wind sectors and the commercial software MeteodynWT [1]. At the current poster, preliminary results using computational fluid dynamics (CFD) simulations of the steady state 3-D Reynolds-Averaged Navier Stokes (RANS) equations with the open-source CFD software OpenFOAM [2] are compared to the met masts measurements.

## Computational domain and boundary conditions

The computational mesh was generated with `blockMesh` and `snappyHexMesh`. The total grid size is 7.7Mi cells, covering a distance of 6 km length, 6 km width and 3 km height. Under the assumptions of neutral Atmospheric Boundary Layer (ABL) stratification, of homogeneous flow and of local equilibrium between the production $k$ and dissipation $\varepsilon$ of turbulence, Eq. 1, 2 and 3 [Table 3] can be used to derive the boundary conditions far upstream at the inlet and at the top [3]. Measurements from the wind mast 1 and over the NW direction (310°) resulted in a $U_{ref}$ = 2.6979 m/s at a reference height $z_{ref}$ = 78 m [Table 2]. The roughness length $z_0$ = 0.8 m was derived from table [Ref. 3], using forest canopy as terrain surface characteristic.

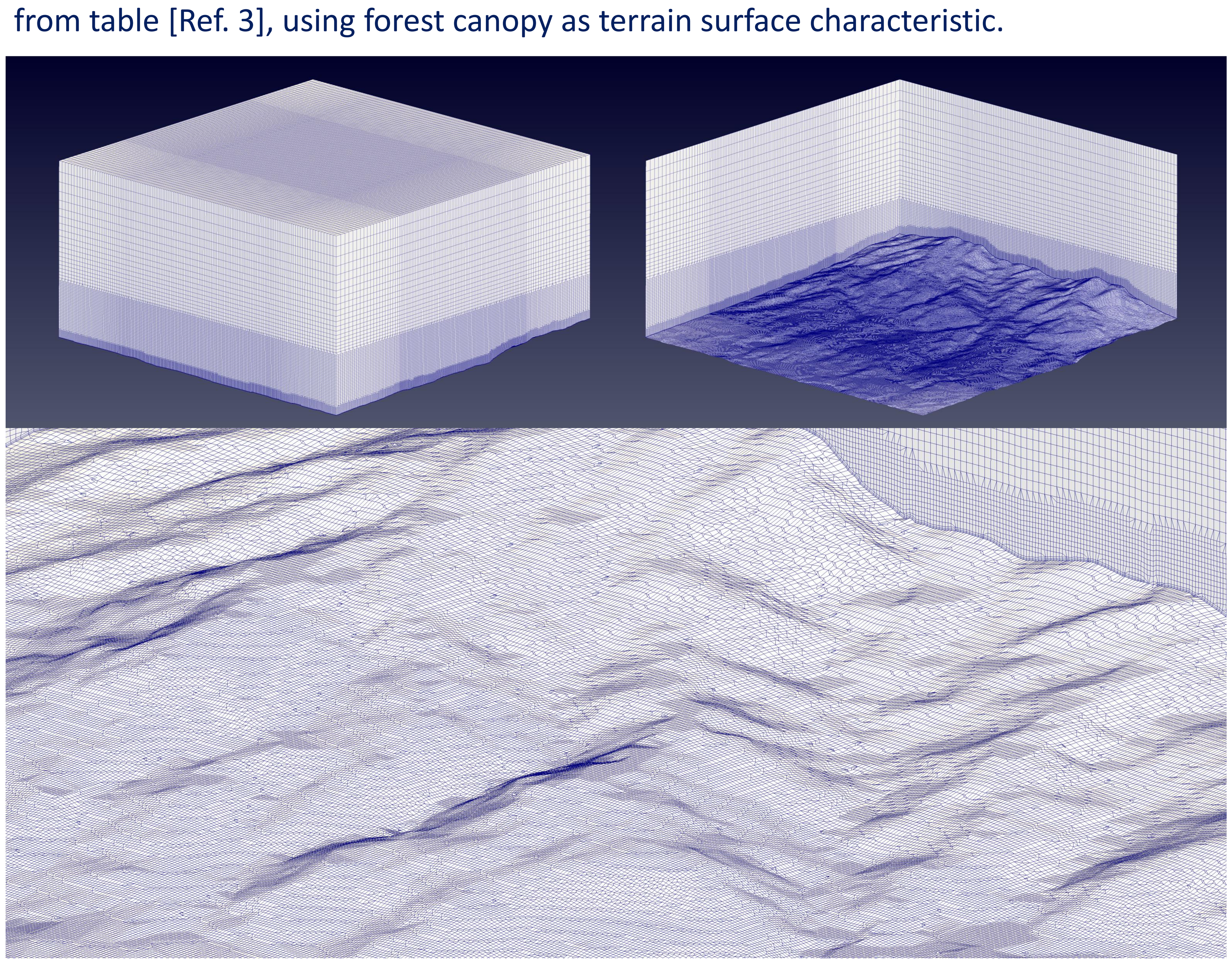

**Figure 1**: . Top: The computational domain including the complex terrain. Bottom: details of the mesh refinement at the ground surface.

**Table 1**: Boundary conditions

| | Dirichlet Fixed value | von Neumann Zero gradient |
|---|---|---|
| Inlet | $U, k, \varepsilon$ | $p$ |
| Top | $U, k, \varepsilon$ | $p$ |
| Outlet | $p$ | $U, k, \varepsilon$ |
| Bottom | ABL wall function | |
| Sides | symmetry conditions | |
| WT | actuator disk model | |

**Table 2**: Initial conditions

| | |
|---|---|
| $U_{ref}$ | 9.37 m/s |
| $z_{ref}$ | 65 m |
| $k$ | 0.3197 m²/s² |
| $\varepsilon$ | 0.00043 m²/s³ |
| $z_0$ | 0.8 m |

**Table 3**: Governing equations

$$u = \frac{u_*}{\kappa}\ln\left(\frac{z+z_0}{z_0}\right) \quad \text{(Eq. 1)}$$

$$k = \frac{u_*^2}{\sqrt{C_\mu}} \quad \text{(Eq. 2)}$$

$$\varepsilon = \frac{u_*^3}{\kappa(z+z_0)} \quad \text{(Eq. 3)}$$

$$u_* = \frac{\kappa U_{ref}}{ln\left(\frac{z_{ref}+z_0}{z_0}\right)} \quad \text{(Eq. 4)}$$

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

| $C_\mu$ | $C_{\varepsilon 1}$ | $C_{\varepsilon 2}$ | $\sigma_\kappa$ | $\sigma_\varepsilon$ | $\kappa$ |
|---|---|---|---|---|---|
| 0.033 | 1.44 | 1.92 | 1.0 | 1.3 | 0.41 |

## CFD approach

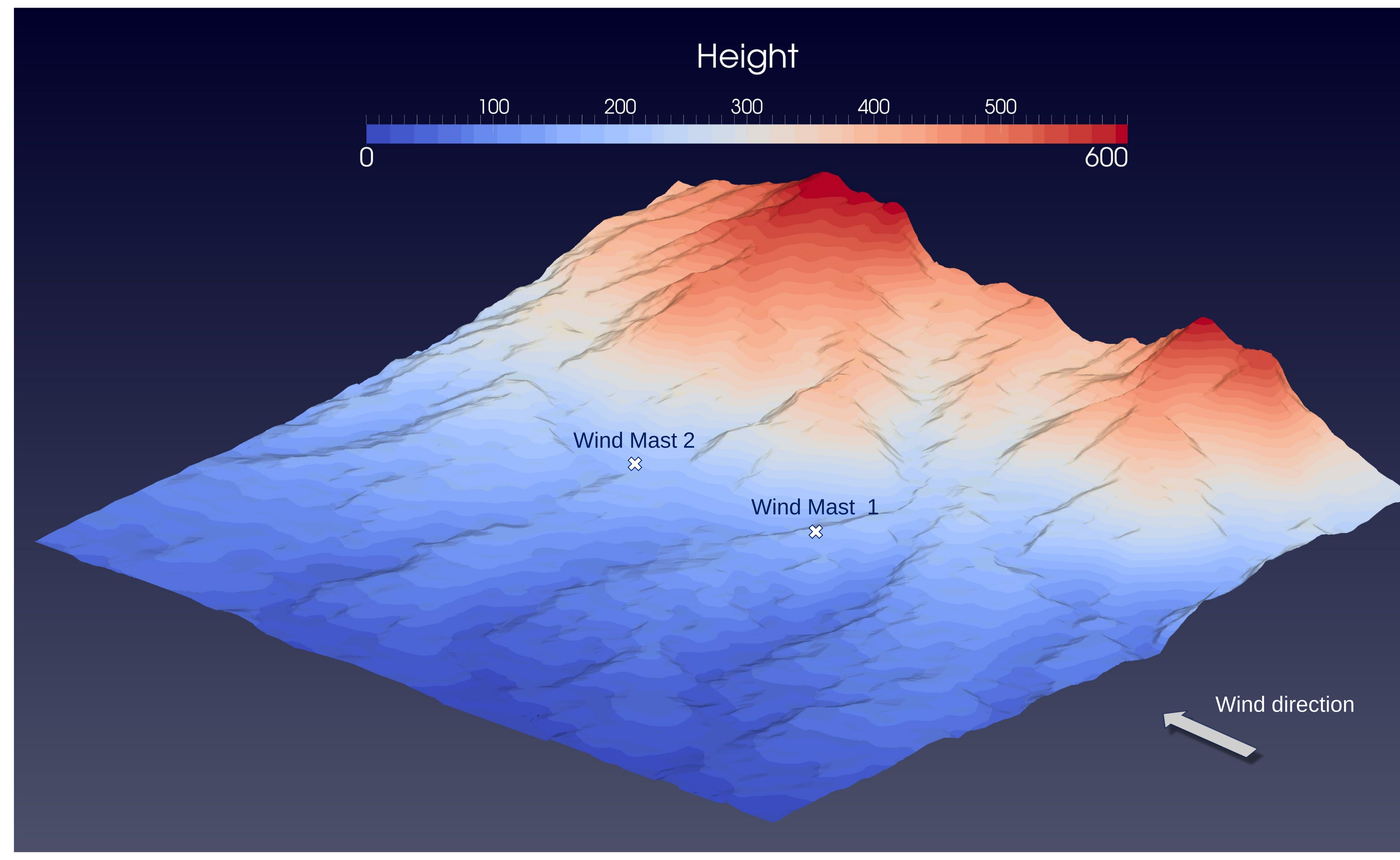


**Figure 2**: Complex terrain elevation and the two meteorological wind masts locations

For the CFD simulations, averaged measurements from the first wind mast [Figure 2] at 78 m height and over the NW direction (310°) were used to derive the initial ABL values [Table 2] and the inlet velocity profile [Figure 3].

The steady state incompressible solver `simpleFoam` was used to resolve the 3-D Reynolds-Averaged Navier Stokes equations. The k-ε turbulence model was chosen with modified closure coefficients [Table 4] for atmospheric conditions [Ref. 5].

CFD simulations converged with 2nd order schemes after 1500 iterations (10 hours on 16 CPUs of 3.3GHz) and ran for 5000 iterations in total.

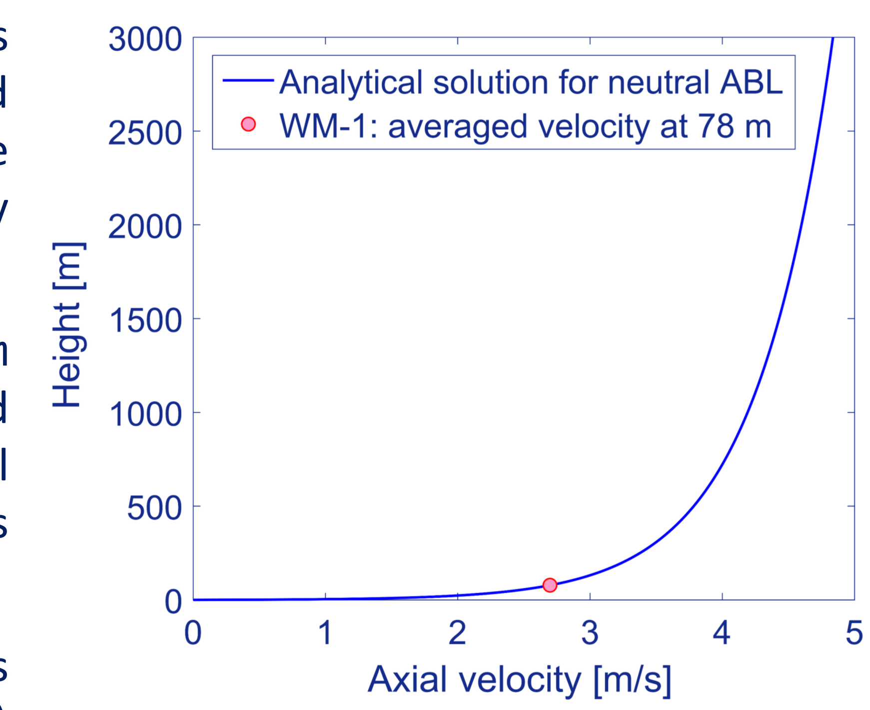


**Figure 3**: Inlet velocity profile

## Preliminary CFD results and discussion

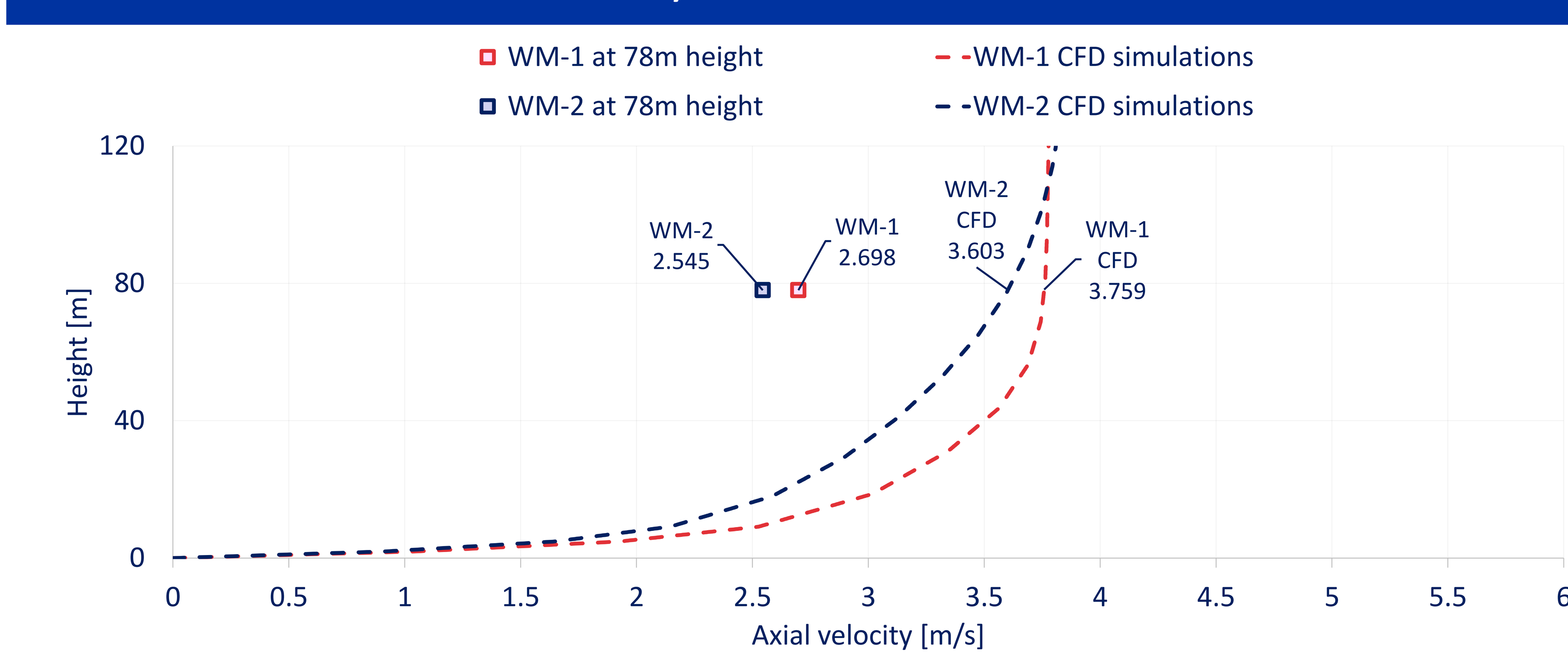


**Figure 4**: Comparison of CFD predictions and wind mast measurements

The case under investigation is over a very complex site. In between the two wind masts there is a dense forest canopy. By using the assumption of a constant roughness length for forest terrain (length $z_0$ = 0.8 m) we were able to predict a velocity difference of **0.156 m/s** at the CFD simulations, similar to the velocity difference that was observed in measurements of **0.153 m/s**. However, the quality of the agreement in the absolute values is much less [Figure 4].

The inlet velocity profile was calculated based on measurements at the first wind mast location. Since there is a very complex terrain upstream with differences in roughness length, the imposed inlet profile will change and adapt to the local terrain effects. Therefore, one future challenge is to impose the correct inlet conditions in order to be able to derive the desired velocity profile at the location of the first wind mast. In addition, the local roughness map and a refined terrain resolution will be included in our simulations and further investigations will be performed using both OpenFOAM and the commercial software MeteodynWT.

## References

[1] MeteodynWT. URL: www.meteodyn.com

[2] Openfoam.org. URL: www.openfoam.org

[3] Hargreaves D. M. and Wright N. G.: On the use of the k–ε model in commercial CFD software to model the neutral atmospheric boundary layer, 2007.

[4] Troen, I., Lundtang Petersen, E.: European Wind Atlas. 1989.

[5] Prospathopoulos J. M., Politis E. S. and Chaviaropoulos P. K.: Modelling wind turbine wake in complex terrain.