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Numerical Modelling of Neutral Atmospheric Boundary Layer Flow over Complex Terrain Covered by the Heterogeneous Forest

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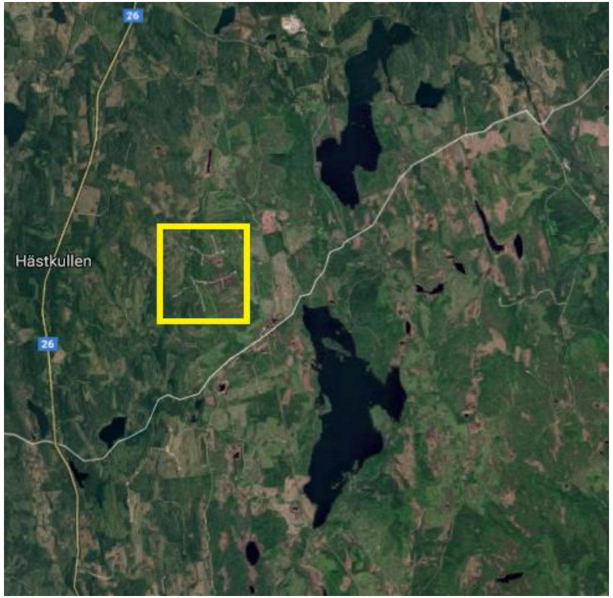
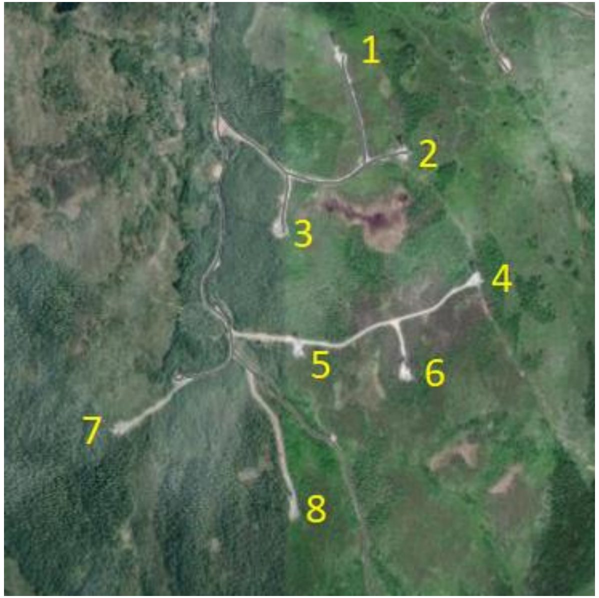
Complex Terrain, Topographical Location

(Röbergsfjället Wind Plant, built in 2007)

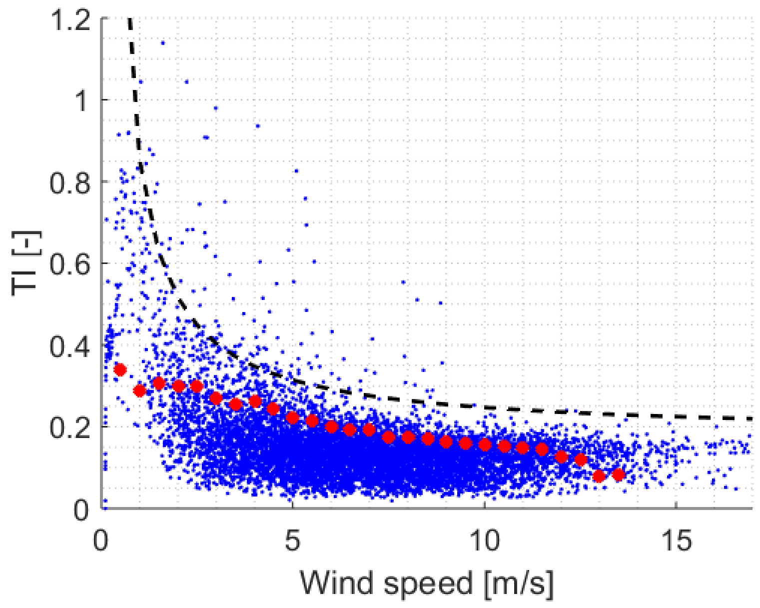


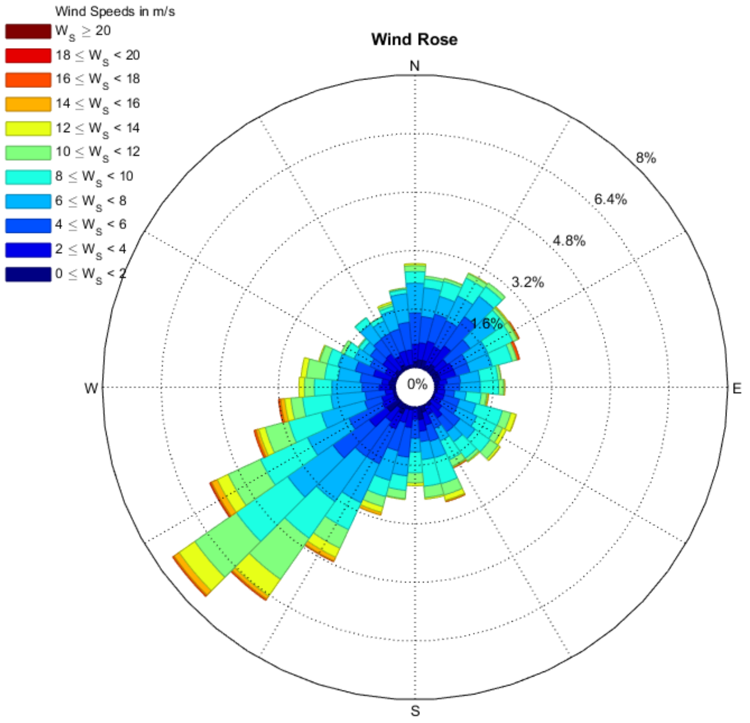


Southern part of Vansbro municipality bordering Ludvika municipality in Dalarna County.

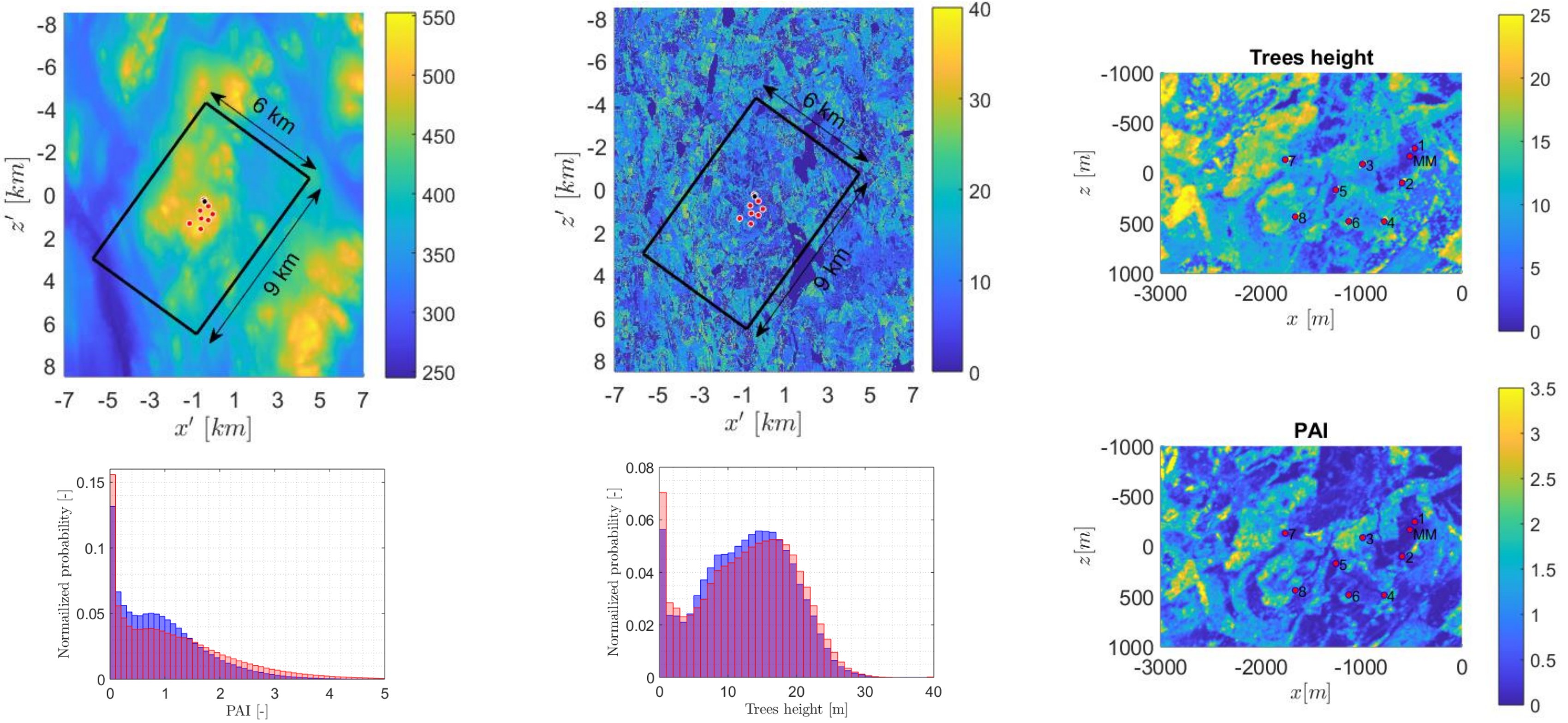
Measurement Data

- Met mast data @ 60 m above ground in 2006 (365 days x 24 hr) without any turbine





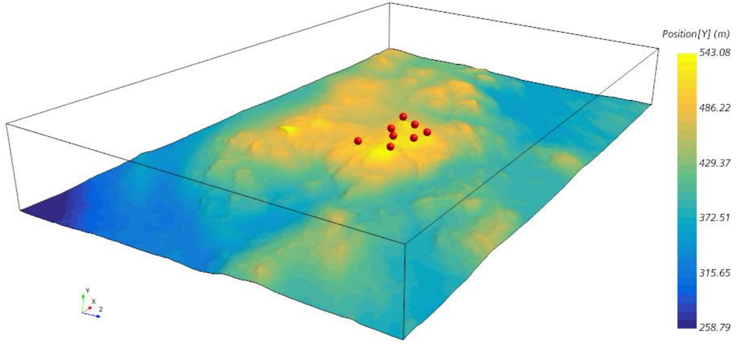
Wind Plant Layout and Forest Properties (216 deg w.r.t North)

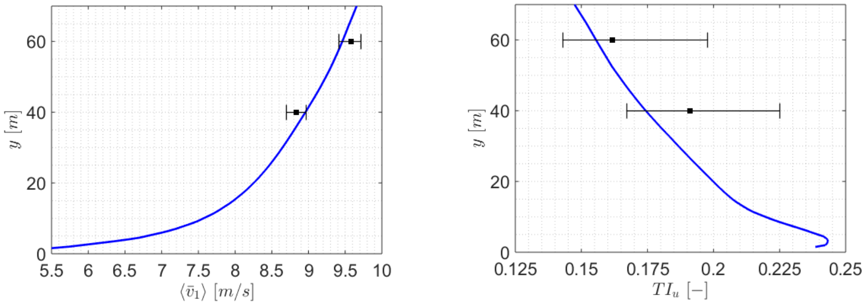


CFD Modelling # 1 (without Turbines' Model)

- Solving incompressible, Navier-Stokes equations using Large-Eddy Simulation (LES) with Standard Smagorinsky sub-grid scale model using STAR-CCM+ software.
- 2nd order time-descretization scheme with constant time step of $\Delta t = 0.1\ s$.
- Domain size, $\mathrm{L} = 9\ km$ x $\mathrm{W} = 6\ km$ x $\mathrm{H} \cong 1.5\ km$.
- Computational grid size, ~*16* million cells (with resolution of $\Delta\mathrm{x} = \Delta z = 17\ m$ in horizontal plane).
- Prism layer height of $\delta y = 207\ m$ including 30 cells in vertical direction with first vertical grid height of $\Delta y = 2\ m$ and $\Delta y = 17\ m$ for the last cell .
- Complex terrain with low aerodynamic surface roughness.
- Heterogeneous forest model.
- Actuator disk model for turbines including wake interaction.
- Neutral atmospheric condition.
- Prescribed wind speed of $6\ m/s$ at $60\ m$ above ground (met mast height).
- Total simulation time of $t = 7260\ s\ \approx 120\ min$
- Sampling collection time of $t = 5460\ s\ \approx 90\ min$

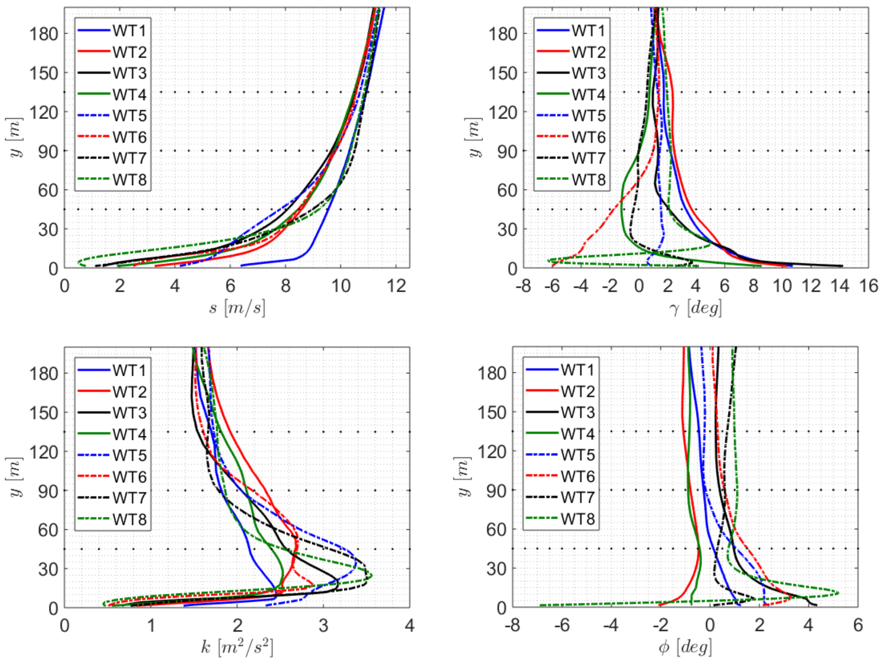
Boundary	Type	Quantity
Inlet	Velocity inlet	Sheared mean profile, synthetic turbulence (turbulence intensity, turbulent length scale)
Outlet	Pressure outlet	P=0
Ground	Wall	Smooth wall
Ceiling/Sides	Symmetry	---



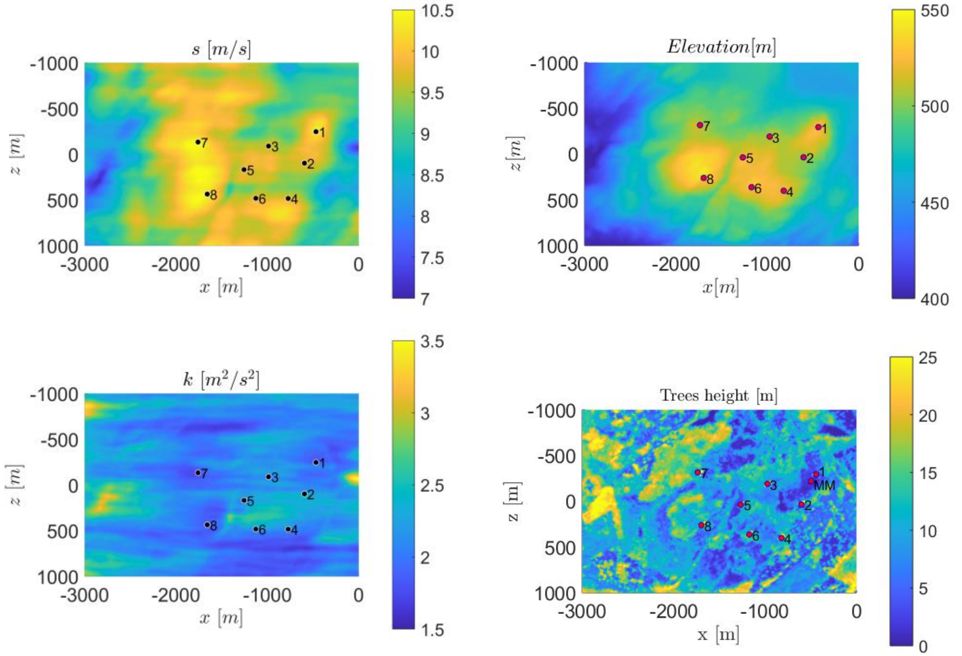


Left) Time-averaged axial wind velocity profile, Right) Streamwise Turbulence intensity, at the met mast location compared with the measurement.

Results, CFD Modelling # 1

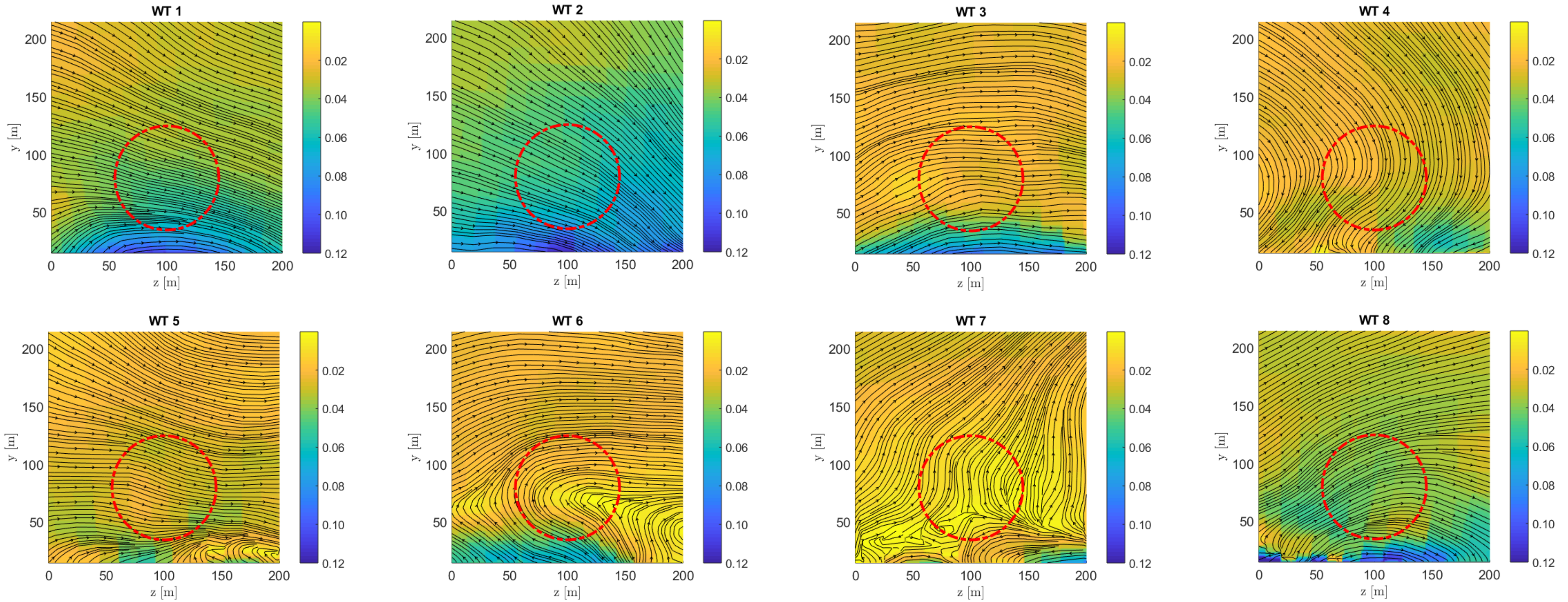


Mean wind speed (s), turbulent kinetic energy (k), mean yaw angle (γ) and mean veer angle (ϕ) at eight turbine locations.



Iso-surface of mean wind speed (s) and turbulent kinetic energy (k) at hub height (90 m above the ground).

Results, CFD Modelling # 1



Streamlines of in-plane mean wind speed around the rotor plane perpendicular to the dominant wind direction colored by $\sqrt{(v_2^2+v_3^2)}/v_1$

A Generic 2.0 MW Turbine Model

- Modelling in the open-source aeroelastic simulator, FAST v8.
- Structural properties relevant to Vestas V90-2.0 MW.
- Controller is based on the 5-MW NREL reference turbine (without “power boost”)

TECHNICAL DATA FOR V90-1.8/2.0 MW

Power regulation — pitch regulated with variable speed

Operating data	IEC IIA	IEC IIIA
Rated power	1,800 kW	2,000 kW
Cut-in wind speed	4 m/s	
Rated wind speed	12 m/s	
Cut-out wind speed	25 m/s	
Frequency	50 Hz/60 Hz	
Operating temperature	standard range -20°C to 40°C low temperature option -30°C to 40°C	

Sound power
(10 m above ground, hub height 80 m air density 1,225 kg/m³)

4 m/s	94.4 dB(A)
5 m/s	99.4 dB(A)
6 m/s	102.5 dB(A)
7 m/s	103.6 dB(A)
> 8 m/s	104 dB(A)

Rotor

Rotor diameter	90 m
Swept area	6,362 m²
Nominal revolutions	14.5 rpm
Operational interval	9.3 - 16.6 rpm
Air brake	full blade feathering with 3 pitch cylinders

Tower

Type	tubular steel tower
Hub heights	80 m, 95 m and 105 m (IEC IIA) 95 m, 105 m and 125 m (DIBt II)

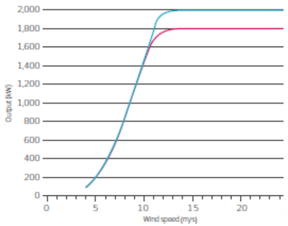
Generator	50 Hz	60Hz
Type	4-pole asynchronous with variable speed	6-pole asynchronous with variable speed
Nominal output	1,800 kW/ 2,000 kW	1,800 kW

Gearbox
Type — 3-stage planetary/helical

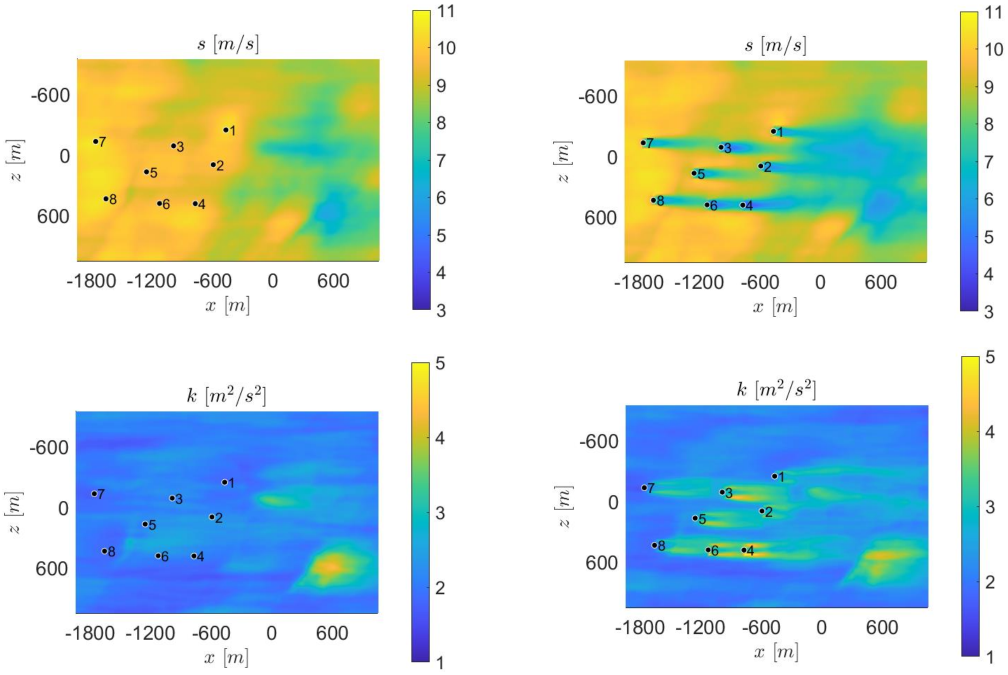
Main dimensions

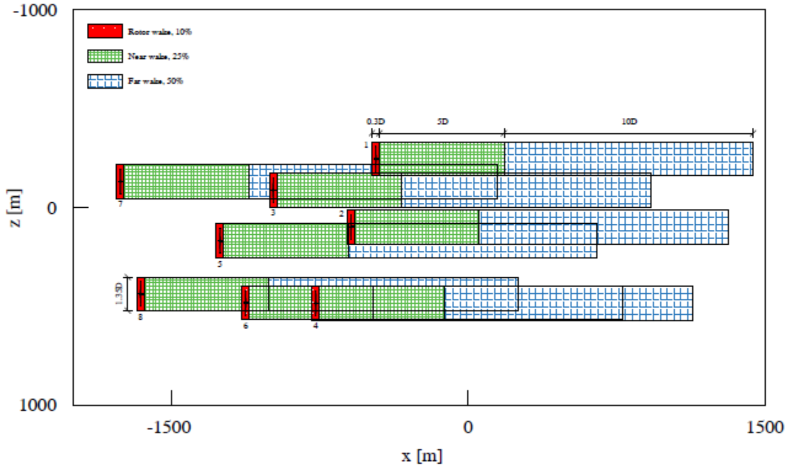
Blade	
Length	44 m
Max. chord	3.5 m
Weight	6,700 kg
Nacelle	
Height for transport	4 m
Height installed (including CoolerTop™)	5.4 m
Length	10.4 m
Width	3.4 m
Weight	70 metric tonnes
Hub	
Max. diameter	3.3 m
Max. width	4 m
Length	4.2 m
Weight	18 metric tonnes
Tower	
80 m	
Weight	148 metric tonnes
95 m	
Weight	206 metric tonnes
105 m	
Weight	245 metric tonnes
125 m	
Weight	335 metric tonnes

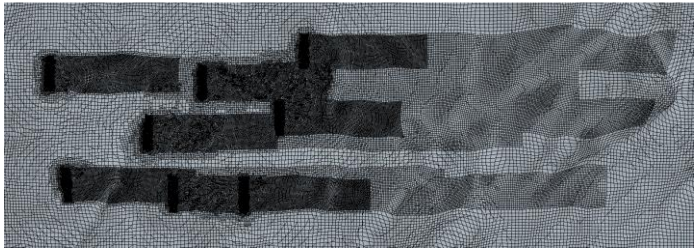
Power curve V90-1.8/2.0 MW
Noise reduced sound power modes are available.



Results, CFD Modelling # 2 (with Actutor Disk Model)







Iso-surface of mean wind speed (s) and turbulent kinetic energy (k) at hub height (90 m above the ground). Left) without AD model, Right) with AD model

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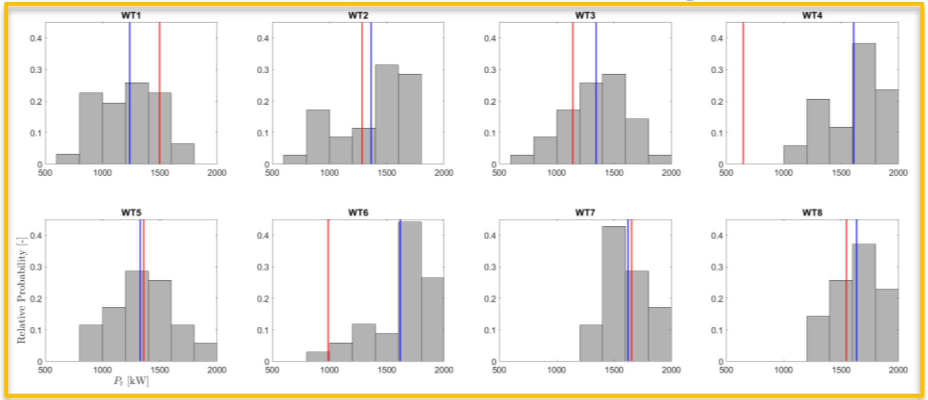
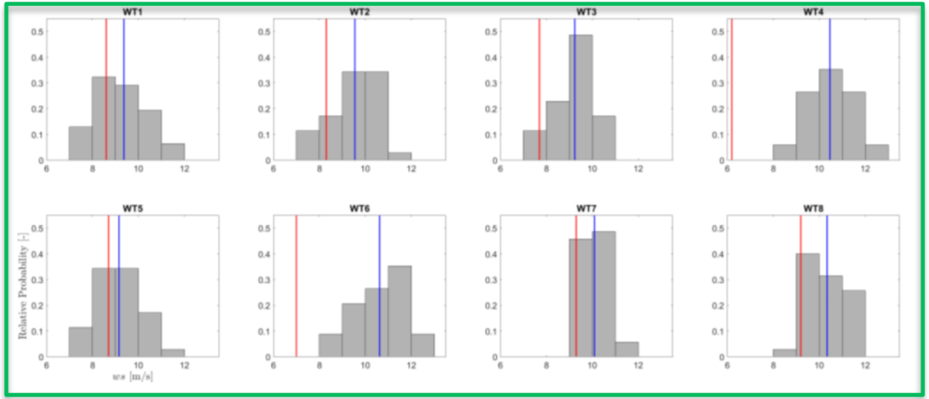
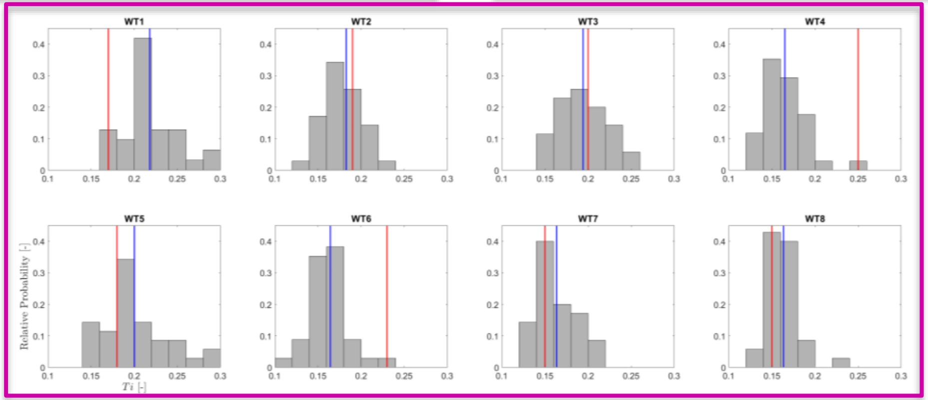
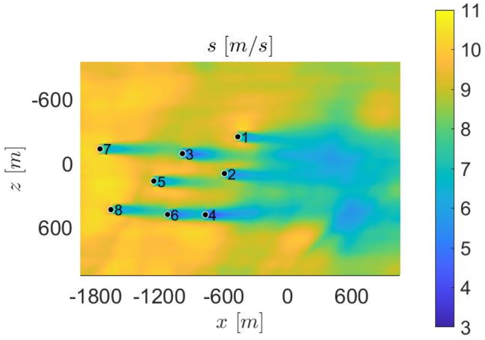
Results, CFD Modelling # 2 vs. Measurement Data





Relative frequency of samples of generated power P_t (top-left), mean wind speed ws (top-right) and turbulence intensity Ti (bottom-middle) collected from neutral conditions (118 days in 2018). **Blue line** is the mean value of the 118 samples from the measurement data and **Red line** is the mean value predicted by the LES simulations.



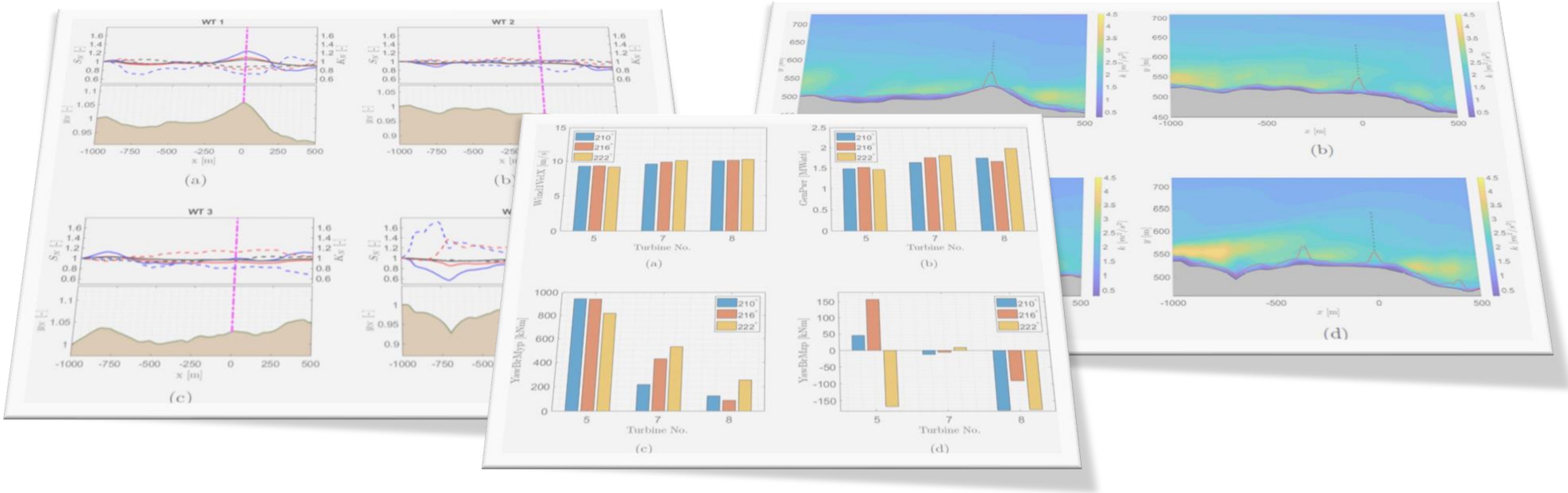


Conclusion

- Employing the Airborne Laser Scanning (ALS) data for the site-specific complex topography and the forest properties may increase the accuracy level for the numerical modeling of airflow.
- A single met mast data might not be a real representative for the wind field of entire wind farm situated in complex terrain increasing the risk of generalization.
- Variation of inflow variables such as mean wind speed, shear exponent and turbulence intensity at each wind turbine location justifies the need for high-fidelity numerical methods to accurately model the airflow inside and over complex terrains and around each wind turbine in a wind farm.
- A higher turbulence intensity is predicted by the homogeneous forest modeling rather than the heterogeneous forest modeling.
- A choice of Actuator Line turbine model may improve the results.

Reference

- Abedi, H.; Sarkar, S.; Johansson, H. Numerical modelling of neutral atmospheric boundary layer flow through heterogeneous forest canopies in complex terrain (a case study of a Swedish wind farm). Renew. Energy 2021, 180, 806-828.



Thanks for Your Attention

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