Wind turbine inflow: Comparison of CFD and WindScanner measurements

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Objectives

- Study induction zone of wind turbines
- Validate actuator disk (AD) RANS simulations by comparing to lidar measurements
- RANS model used to derive simple models

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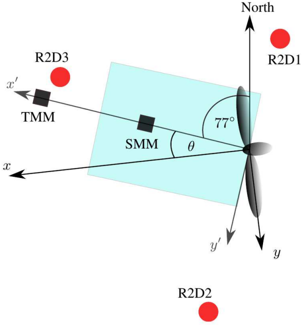
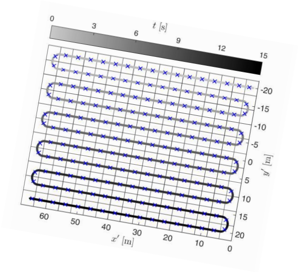
UniTTe-NTK measurement campaign

Synchronized triple lidar (WindScanner) measurements upstream of a Nordtank (NTK) 500 kW turbine

- Turbine radius, R=20.5 m
- WindScanner sweeps horizontal plane ($3.1R \times 2.0R$) in approximately 15 s



R2D1, R2D2, R2D3: lidars; TMM/SMM: tall/short met mast (4.5R/2.3R upstream)



Triple lidar scanning pattern

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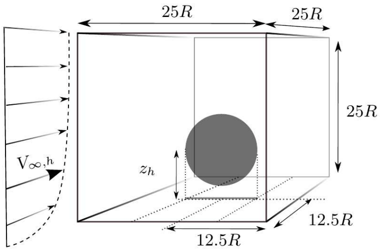
Simulation set-up

- Steady state RANS ($k - \epsilon$ turbulence model)
- Actuator disk (AD) representation of rotor
- Flat terrain
- Logarithmic inflow velocity
- Roughness length $z_0 = 0.055$



Sketch of computational domain

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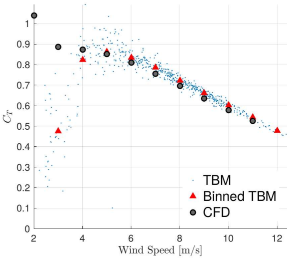
Initial comparison: Standard approach

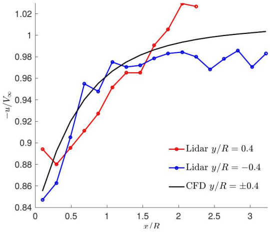
Procedure:

- Estimate U_∞ and wind direction from TMM
- Sort and average WindScanner data according to U_∞ and wind direction
- Run CFD simulation at same average conditions

Conclusions:

- Thrust coefficient compares well
- Similar trends
- Better agreement at $y/R = -0.4$ than $y/R = 0.4$
- Does not really validate the model
- Not enough data (approximately 5.5h)





Comparison of upstream velocity

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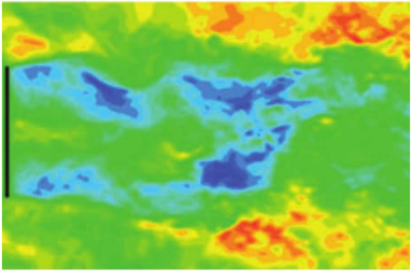
Alternative approach: LES

- Estimate the actual inhomogeneous and unsteady inflow from measurements
- Run unsteady LES with similar inflow conditions

Drawbacks:

- Computational heavy
- Very difficult to get the same inflow (including spectra) conditions
- Statistical dependence



Unsteady wake predicted using LES

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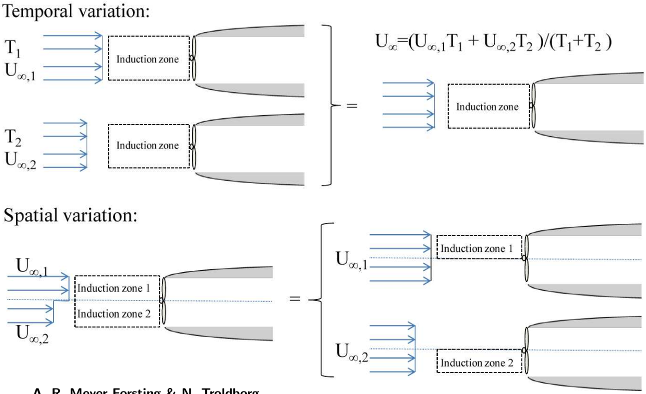
Alternative approach: Quasi-steady simulations

- Estimate the actual inhomogeneous and unsteady inflow from measurements
- Characterize the free-stream velocity by its spatially varying PDF
- Run steady state RANS and weight according to the free-stream PDFs
- Similar to simulating AEP of wind farms



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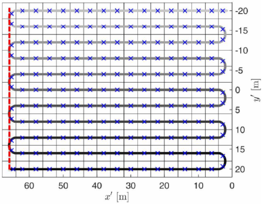
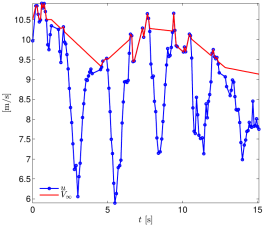
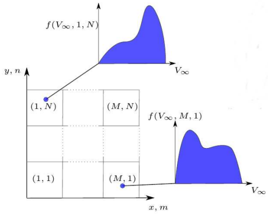
Estimating the free-stream velocity

- Measured free-stream velocity estimated by interpolation (virtual lidar)
- Free-stream velocity varies in time and space
- The free-stream velocity is characterized by its PDF in each cell







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Uncertainties

Uncertainties affects the spread of the PDF

- Wind variability
- Induced velocity (accounted for with simple vortex model)
- Yaw direction θ (affects velocity projection and position in rotor coordinates)
- Non-trivial to include all uncertainties

The spatially varying PDF of the free-stream velocity including uncertainties:

$$f(\mathbf{V}_\infty, \theta, m', n'; m, n) = \frac{\int_{y^-}^{y^+}\int_{x^-}^{x^+}\int_{-\infty}^{\infty} f\left(\mathbf{V}_\infty, \theta, m', n'; \mathbf{x}, t\right) f(\mathbf{x}; t) p(\mathbf{x}, t)\, \mathrm{d}t\, \mathrm{d}x\, \mathrm{d}y}{\int_{y^-}^{y^+}\int_{x^-}^{x^+}\int_{-\infty}^{\infty} f(\mathbf{x}; t) p(\mathbf{x}, t)\, \mathrm{d}t\, \mathrm{d}x\, \mathrm{d}y}$$

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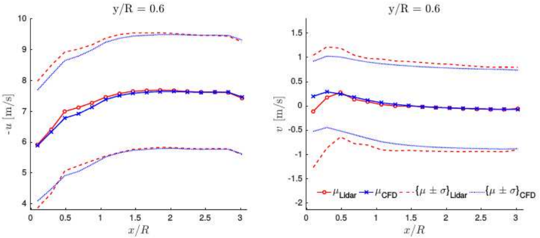
Comparison of CFD and measurements

- Steady state RANS conducted at different free-stream velocities
- Solution sampled as the WindScanner (numerical WindScanner)
- The solutions are weighted according to the measured free-stream velocity PDF
- Agreement is excellent



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Conclusions

- Important to account for variability in inflow velocity
- Important to account for uncertainties
- AD-RANS predicts the rotor induction accurately