Experimental and Numerical study of Wake to Wake Interaction in Wind Farms

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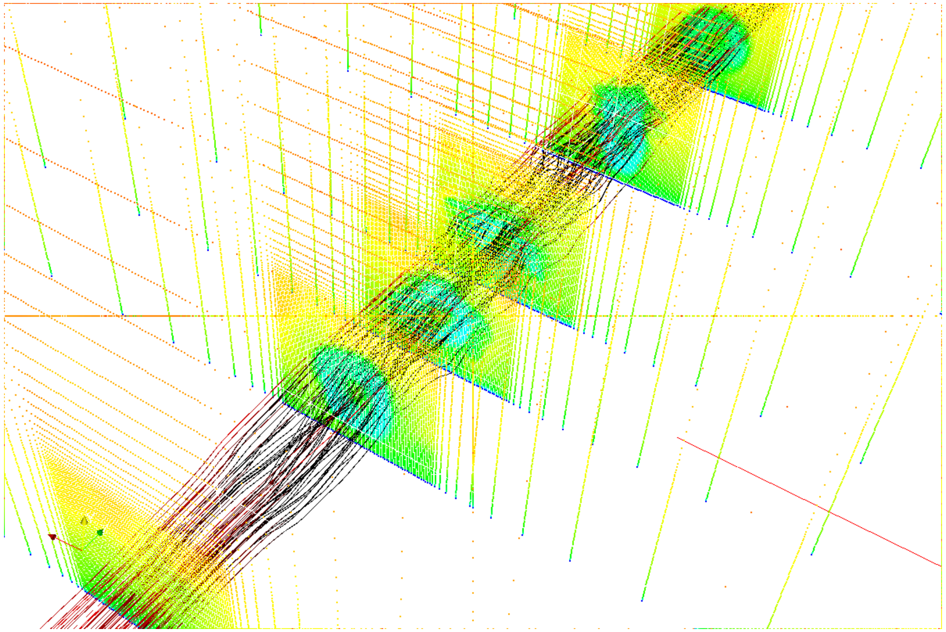
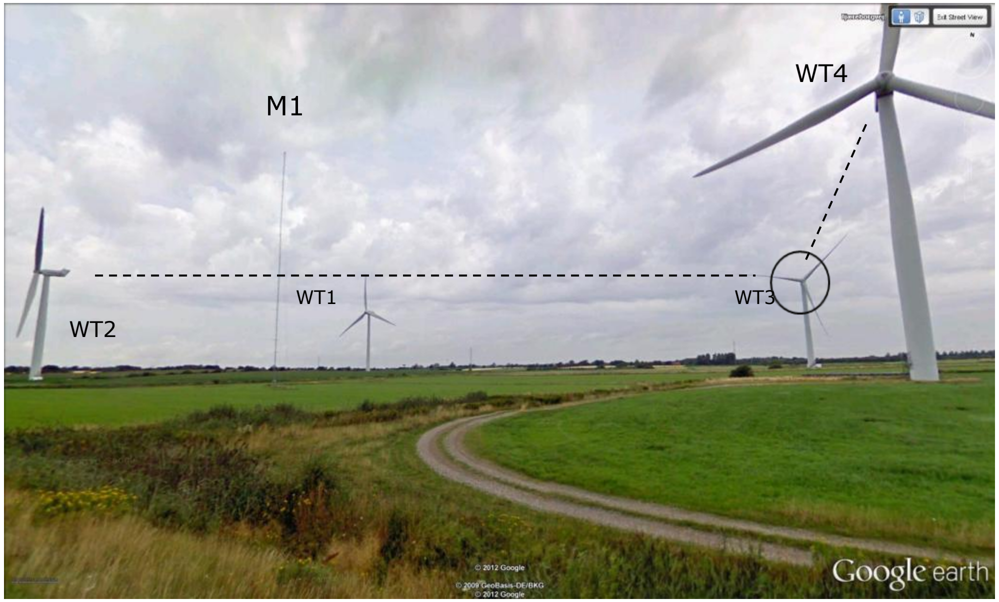


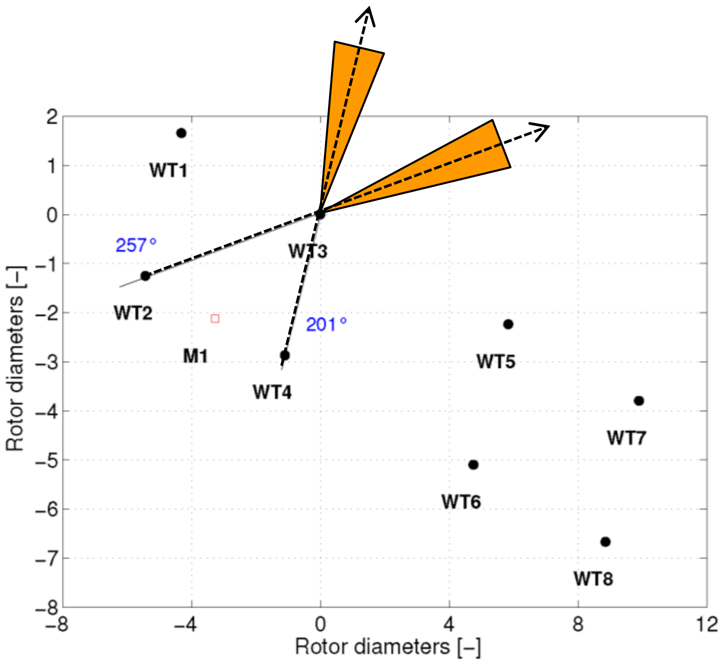
Summary

1. Experimental approach
2. Numerical approach
3. Comparison results and discussion
4. Future work

1 - Experimental approach: Tjæreborg site

- Tjæreborg EU-TOPFARM full scale LIDAR based measurements campaign
  - Several hours of single, half and full wake situations recorded in 2009
  - WT3 LiDAR mounted



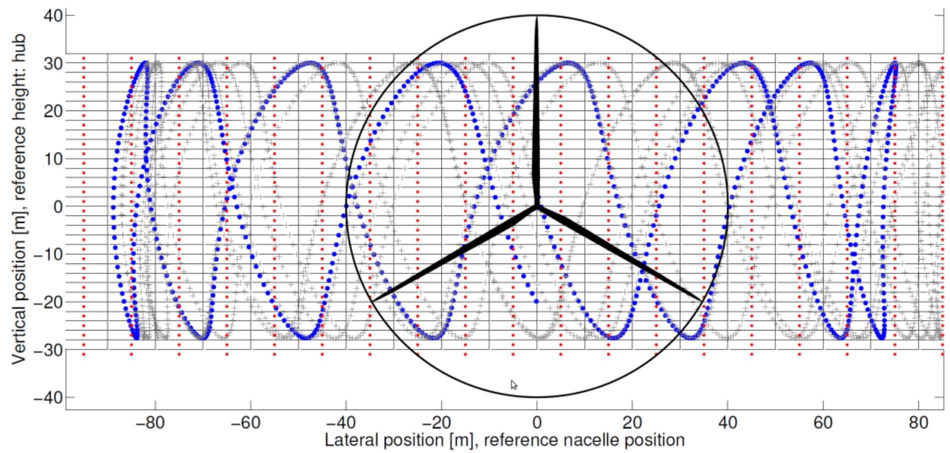


1 - Experimental approach: wake resolving

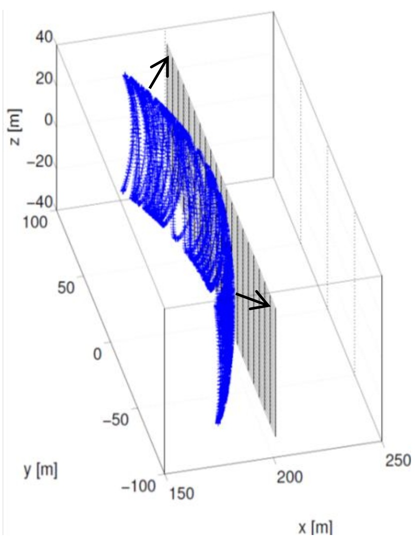
- CW Focus LiDAR System adapted, 348 Hz
- Methodology for wake resolving:

1. Computation from Doppler Spectra to line-of-sight velocity Vlos
2. Filtering of erroneous measurements
3. Discretization: 2 x 10 m² (cell center in red)
4. Additional correction for laser beam tilt and pan angles

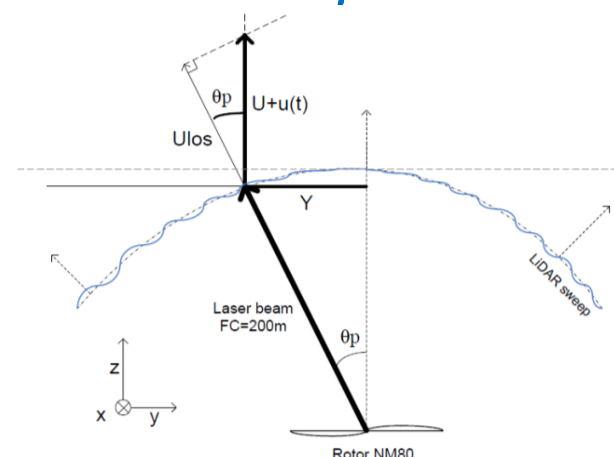
Scanning pattern of CW LiDAR



Measurement volume



Correction for tilt and pan of laser beam

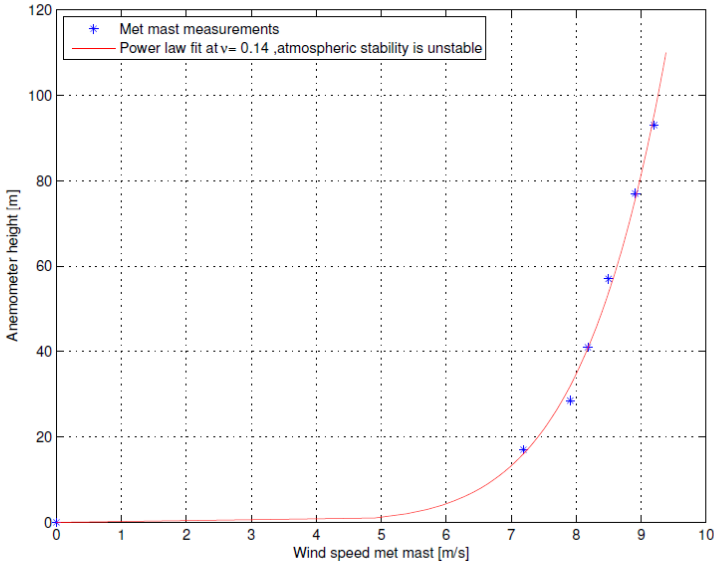


$$U_{LiDAR} = U_{los} \cdot \frac{1}{\cos \arcsin\left(\frac{Y}{FC}\right) \cos \arcsin\left(\frac{X}{FC}\right)}$$

1 - Experimental approach: test cases

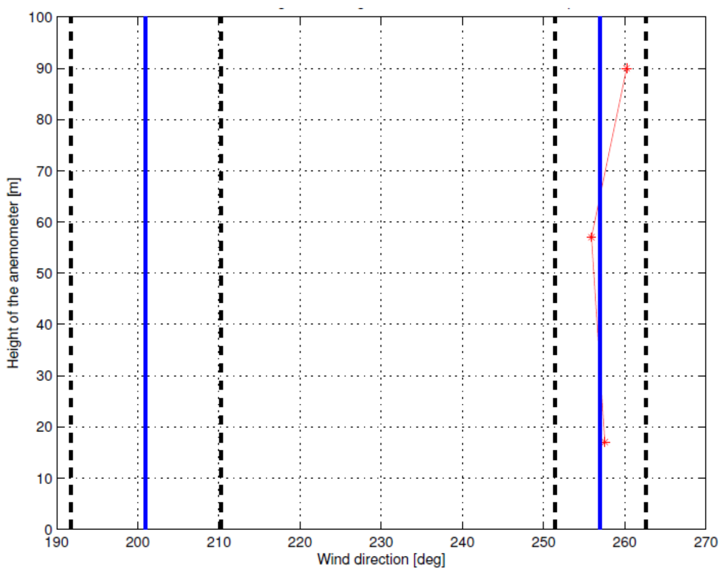
2 double wakes investigated

Site measurements	WT2-WT3	WT4-WT3
Wind speed [m/s]	8.50	7.24
Shear coef. [-]	0.14	0.08
Inflow turbulence level [-]	0.05	0.03
RPM upstream [-]	15.00	15.90
RPM downstream [-]	13.15	12.22
Turbine separation [m]	446 ≈5.5D	246 ≈3D
LiDAR Focus distance [m]	200	200



Full wake
WT4 / WT3

Full wake
WT2 / WT3



Selection criteria

→Low turbulence level

→Neutral atmospheric stability (based on temp. measurement and Obukhov length)

→Ensure perfect wind alignment by plotting average wind direction for 3 heights

→ Moderate wind for high thrust

→ Low yaw misalignment (assumed)

2 – Numerical approach: computational set up

Numerical set up

- EllipSys3D flow solver [2]
- Rotor modeled using Actuator Line Technique [3]
- LES turbulent model
- Atmospheric boundary layer modeled in 2 parts:
    - shear: steady body forces computed and applied in the entire domain
    - synthetic turbulent fluctuations inserted in a cross section upstream of the rotor [4]
- 2 grids (3.98M & 2.95M cells)

[2] N. N. Sørensen and W. Z. Shen. General purpose flow solver applied to flow over hills, PhD Thesis, Risø National Laboratory. *Wind energy*, 1995.

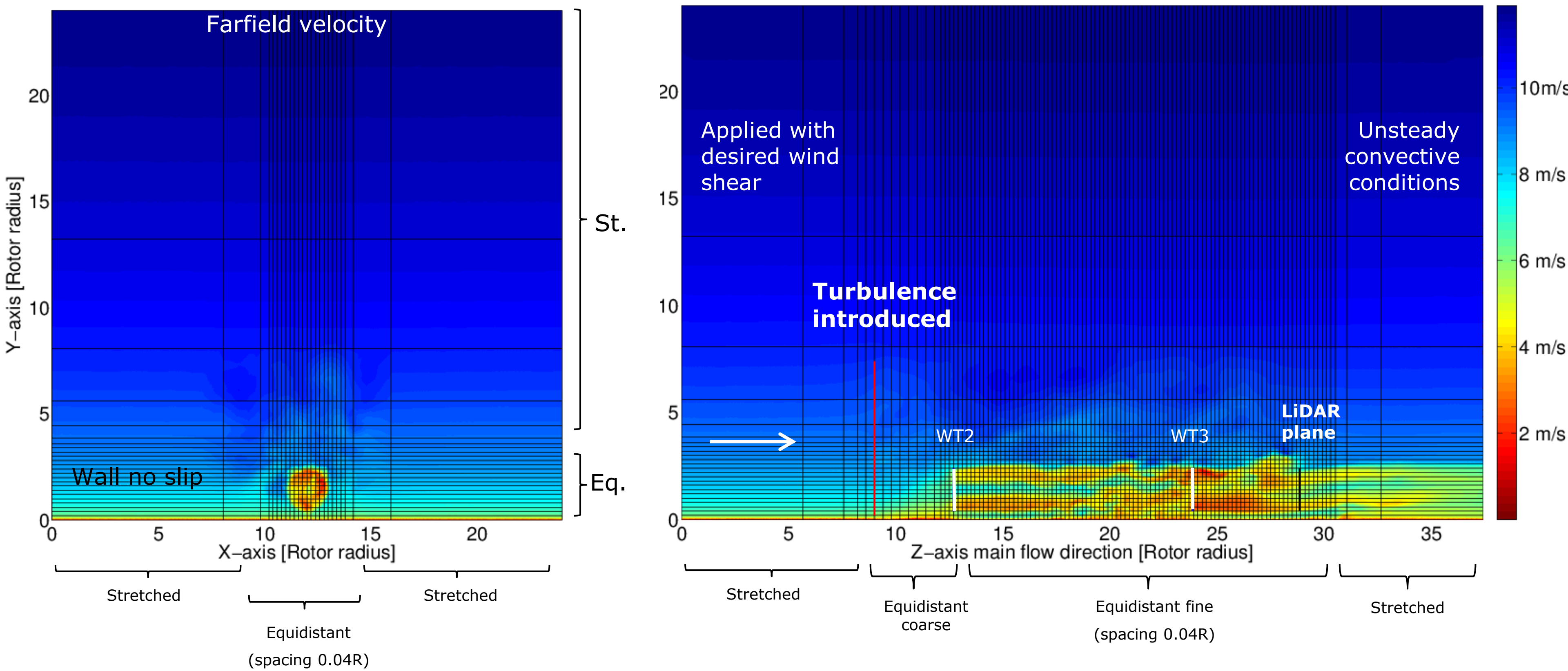
[3] J. N. Sørensen and W. Z. Shen. Numerical modeling of Wind Turbine Wakes, Fluids Engineering, Vol 124, Issue 2. *Wind energy*, 2002.

[4] J. Mann. The spatial structure of neutral atmospheric surface-layer turbulence. *Journal of fluid mechanics*, pages 273, 141–168, 1994.

2 – Numerical approach: computational grid

Non uniform Cartesian grid (4th grid level shown of larger grid)

Size: (Lx,Ly,Lz)=(24R, 24R, 37.4R)= (960m, 960m, 1496m)

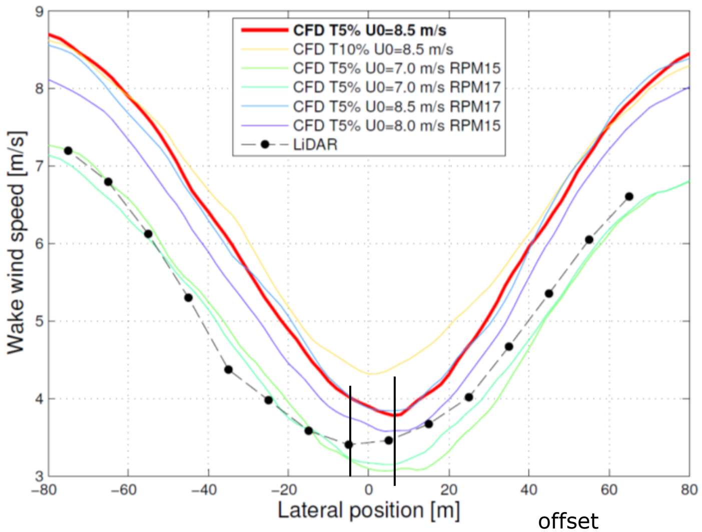


→ Unsteady computations until 10 minutes flow field statistic can be extracted

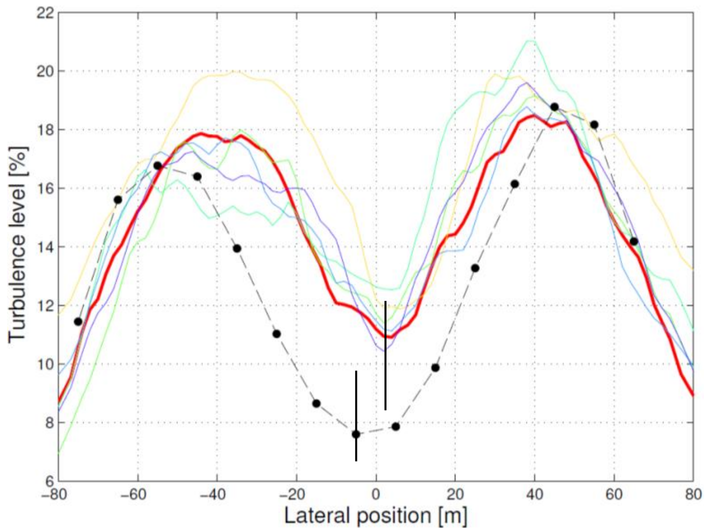
3 – Results: case 1

Merged wake at 2.5D downstream and ≈5.5D turbine spacing

Streamwise wake velocity at hub height



Streamwise wake turbulence level at hub height



Sensitivity analysis:

- uncertainty on real free stream velocity
- computations at measured parameters inconsistent in terms of power produced
- offset in the yaw sensor of more than 12 degrees
- RPM sensor of upstream turbine: integer format

TI [%]; U0 [m/s]; RPM [-]	Rel. error WT4 [%]	Rel. error WT3 [%]	Rel. error power ratio [%]
5%; 8.5m/s; 15 (measured)	13.20	18.34	5.92
10%; 8.5m/s; 15	5.52	35.16	31.37
5%; 7.0m/s; 15	56.03	47.60	5.41
5%; 7.0m/s; 17	47.04	34.74	8.37
5%; 8.5m/s; 17	9.14	19.10	10.97
5%; 8.0m/s; 15	2.84	3.43	6.09

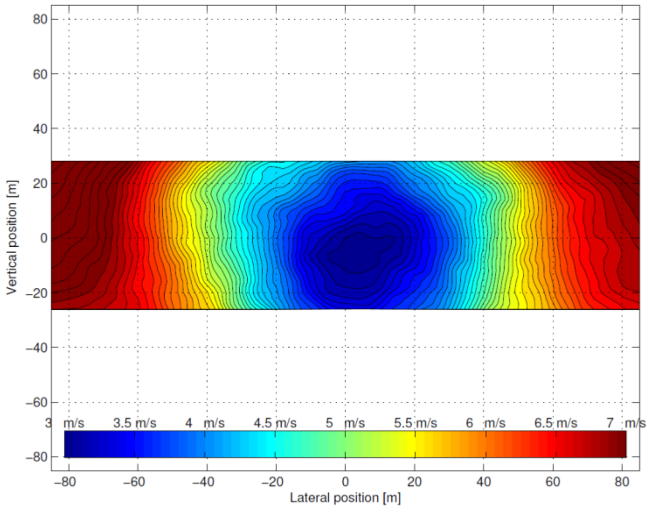
$$\epsilon = 100 \cdot \left| \frac{P_{EllipSys3D} - P_{meas}}{P_{EllipSys3D}} \right|$$

3 – Results: case 1

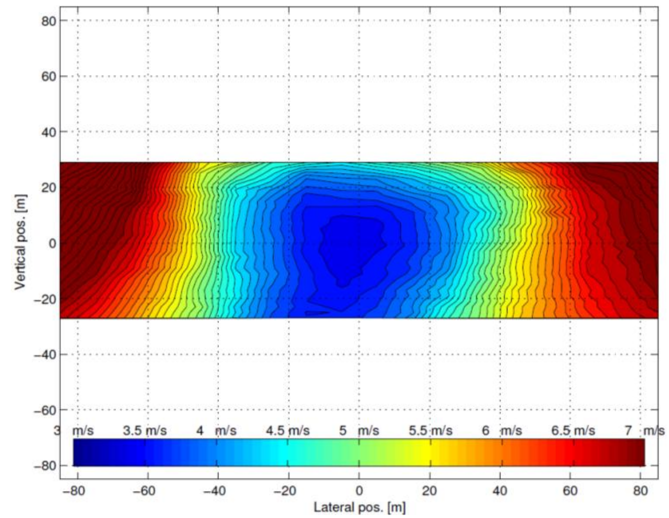
Merged wake at 2.5D downstream and ≈5.5D turbine spacing

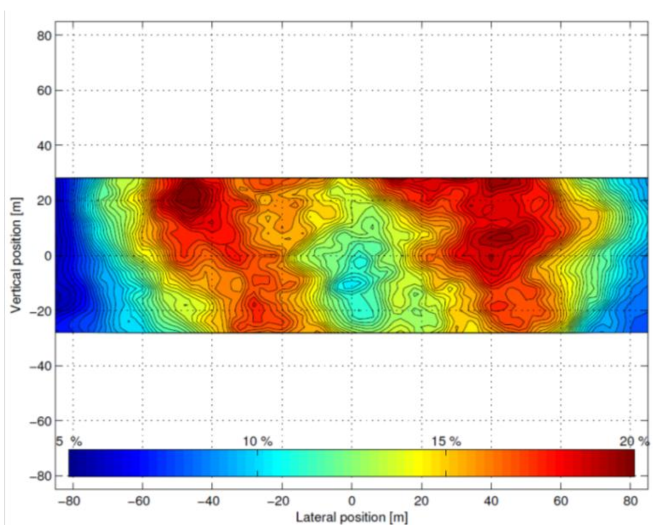
Streamwise wake velocity

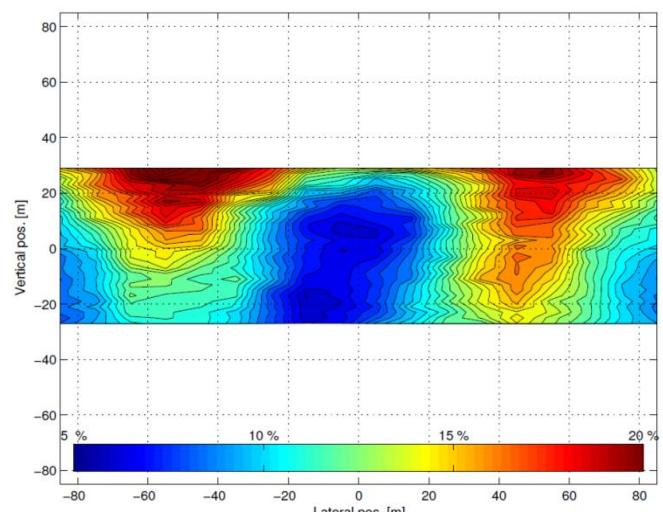
EllipSyS3D



Measured LiDAR



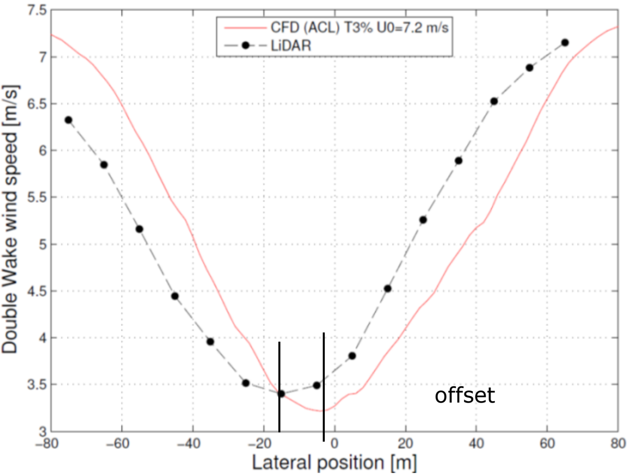




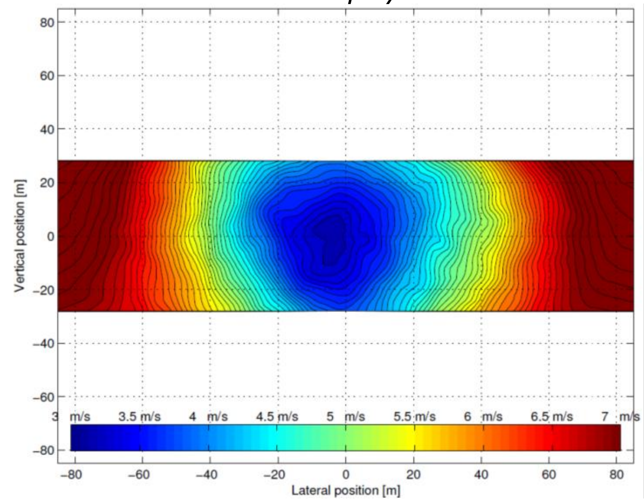
3 – Results: case 2

Merged wake at 2.5D downstream and ≈3D turbine spacing

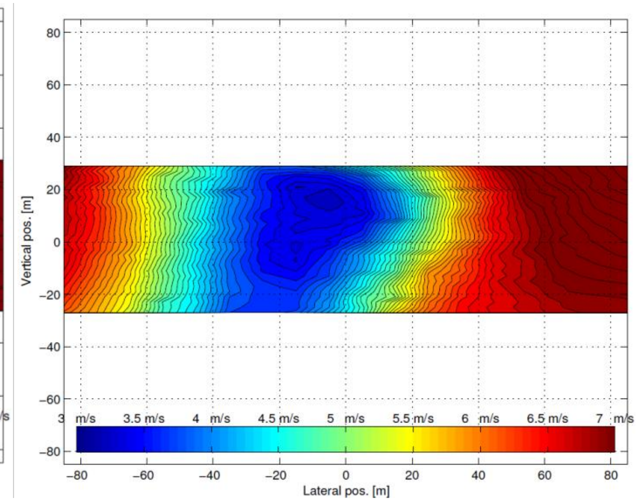
Streamwise wake velocity at hub height

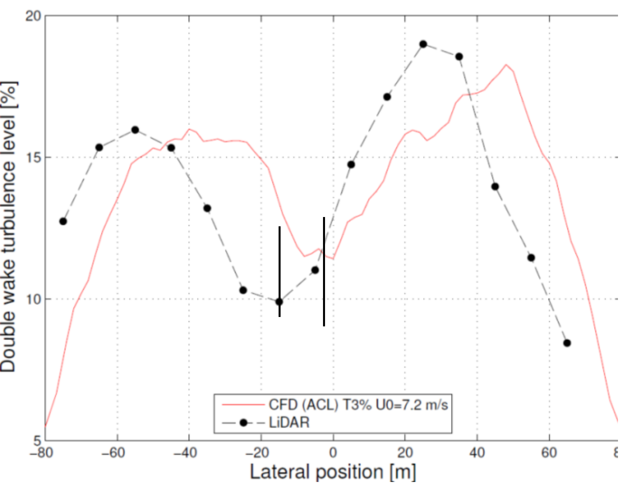


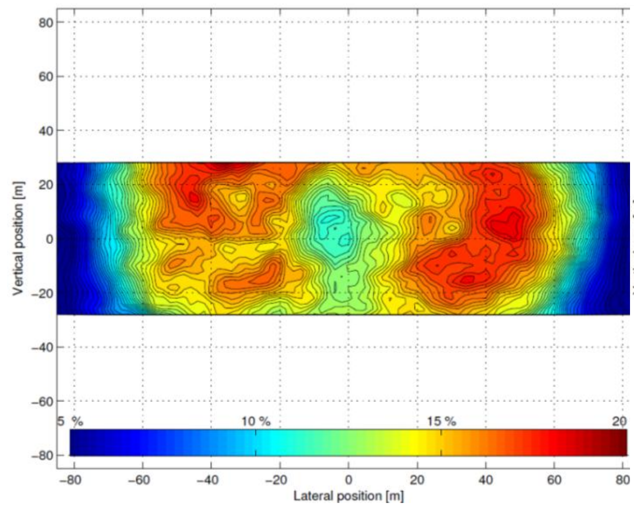
Streamwise wake velocity contour – EllipSyS3D

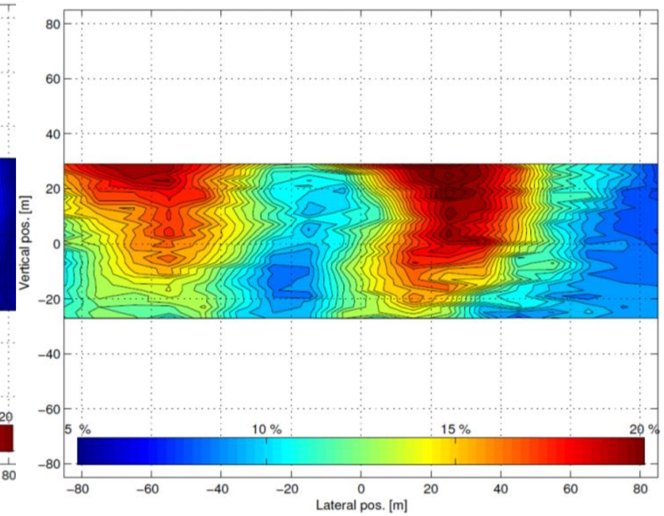


Streamwise wake velocity contour – Measured LiDAR









4 – Conclusions (1)

Analysis from Tjæreborg experiment:

• Good agreements on organized flow structure part of the wake

… but limitations

• Analysis restricted to average quantities due to limitation in time and spatial resolution in the measured wake

• Uncertainties on the inflow

• Analysis only in the fixed frame of reference and at one downstream cross section

Future work

• *Add comparison with the DWM model using assumptions on merging wake*

• *New merged wake experiment*

4 -Future merged wakes experiment

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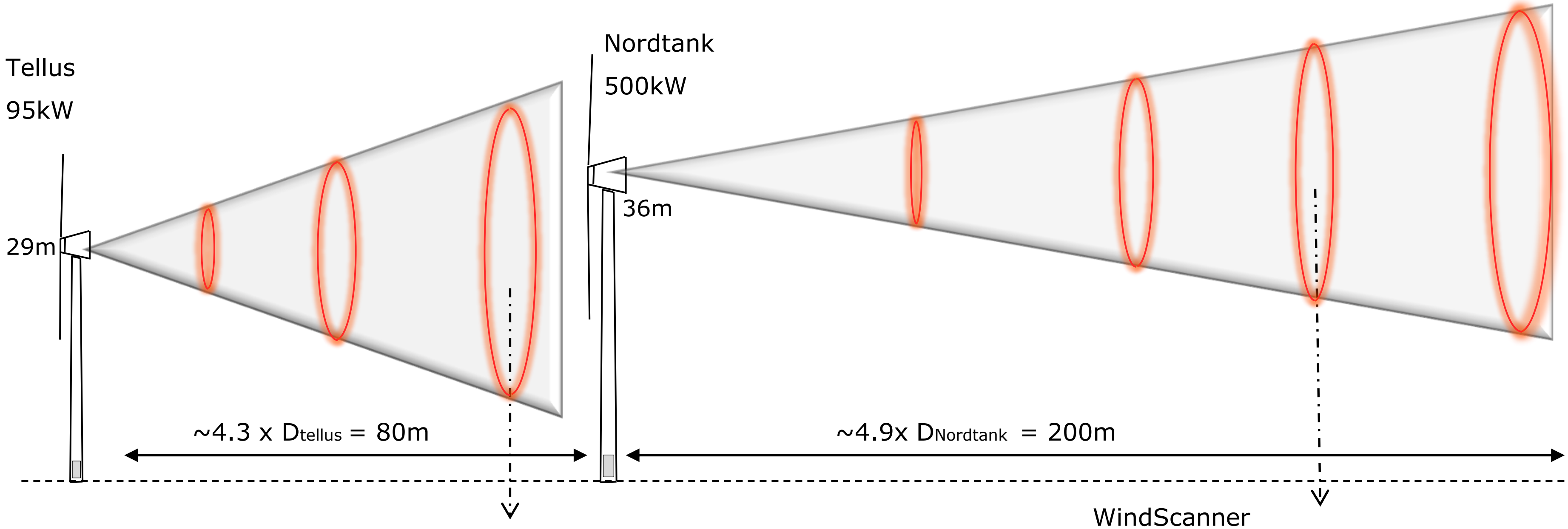
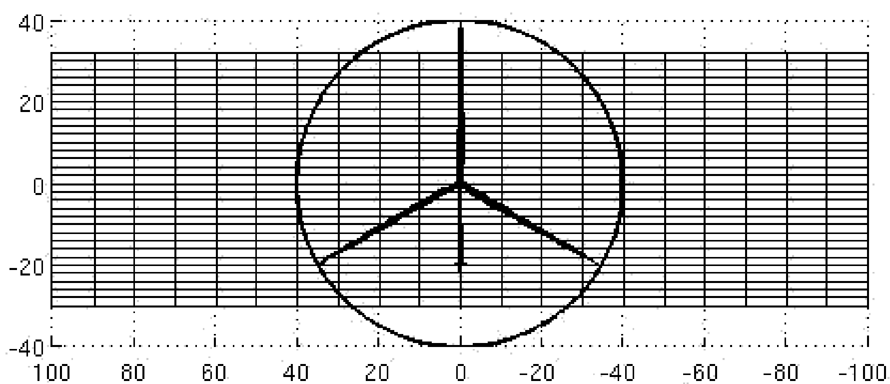
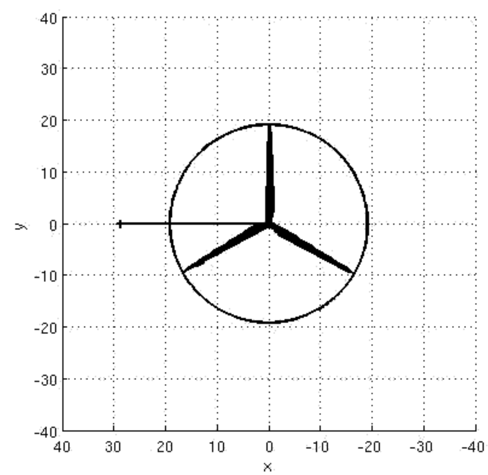


CW LiDAR



WindScanner



4 – Conclusions (2)

Future experiment:

• turbulence content, meandering, expansion and recovery of the wake can be investigated

• several plane can be scanned at a time

• the use of 2 LiDARS will enhance knowledge of the inflow to the downstream turbine

Questions?

Thanks for your attention