LIDAR MEASUREMENTS OF FULL SCALE WIND TURBINE WAKE CHARACTERISTICS

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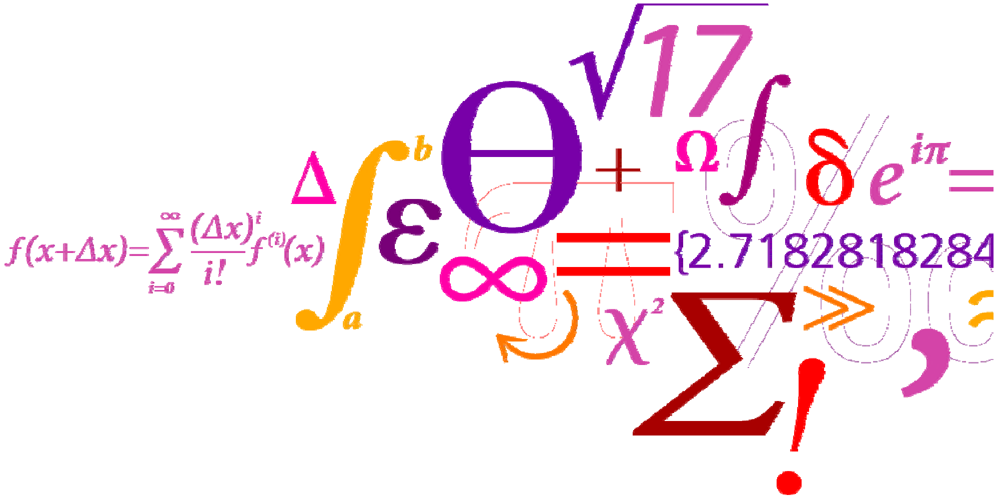


DTU Mechanical Engineering
Department of Mechanical Engineering

Outline

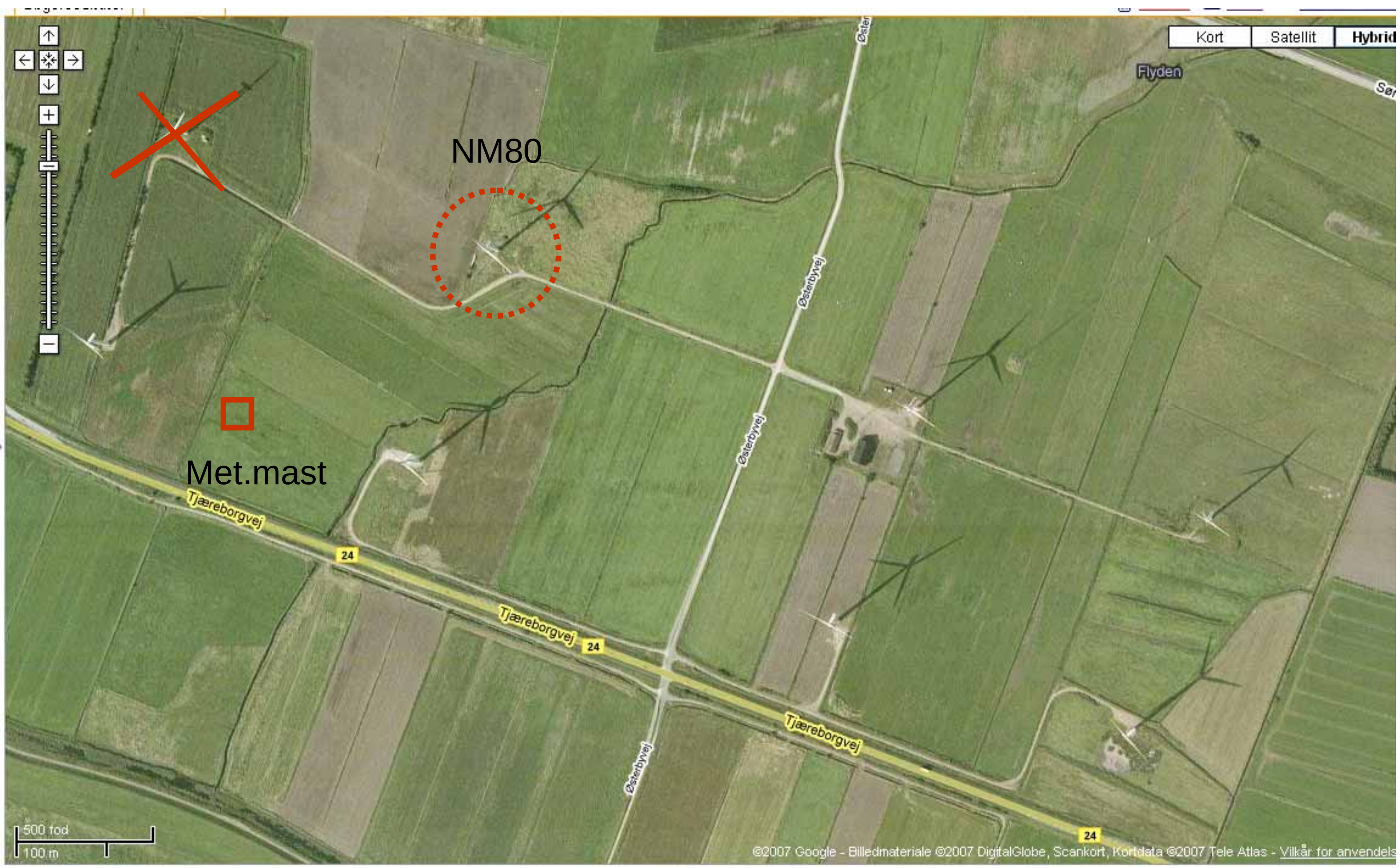
- Purpose
- Site layout
- Measurement setup
- Preliminary wake measurements
- Data analysis
  - Eliminate shear
  - Identify wake meandering
  - Resolve wake deficit in meandering frame of reference
  - Resolve inhomogeneous wake turbulence intensity characteristics
- Conclusion
- Acknowledgements
- Announcement

Purpose

- Perform full-scale wind speed measurements in the wake of an operating 80m / 2.5 MW wind turbine.
- Resolve the wake meandering caused by the <u>large scale part</u> of the ambient turbulence field
- Resolve the wake characteristics in the meandering frame of reference, i.e.
  - Wake deficit
  - Inhomogeneous wake turbulence intensity characteristics

Reference project is EU-TOPFARM.

Site layout


NM80
Met.mast
Kort
Satellit
Hybrid
Flyden
Tjæreborgvej
24
Østerbyvej
500 fod
100 m
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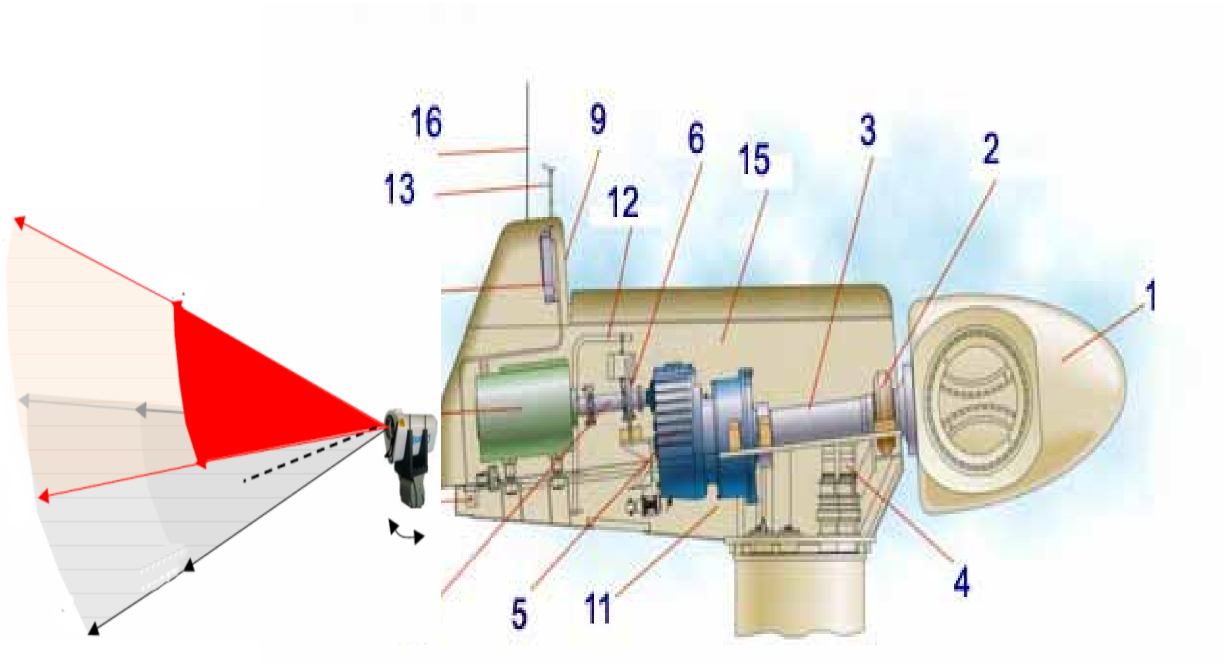
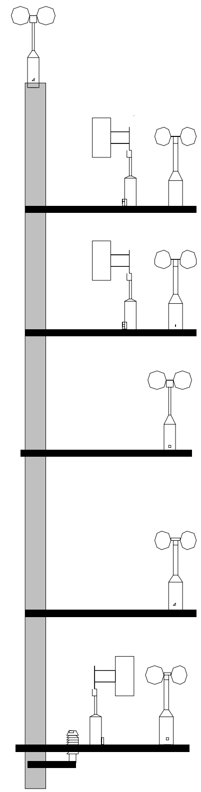
Wake measurements with a horizontally shooting LiDAR (1)





NM80; 80m / 2.5MW; VP & VS

Wake measurements with a horizontally shooting LiDAR (2)

LiDAR Performance (Experimental QinetiQ ZephIR):

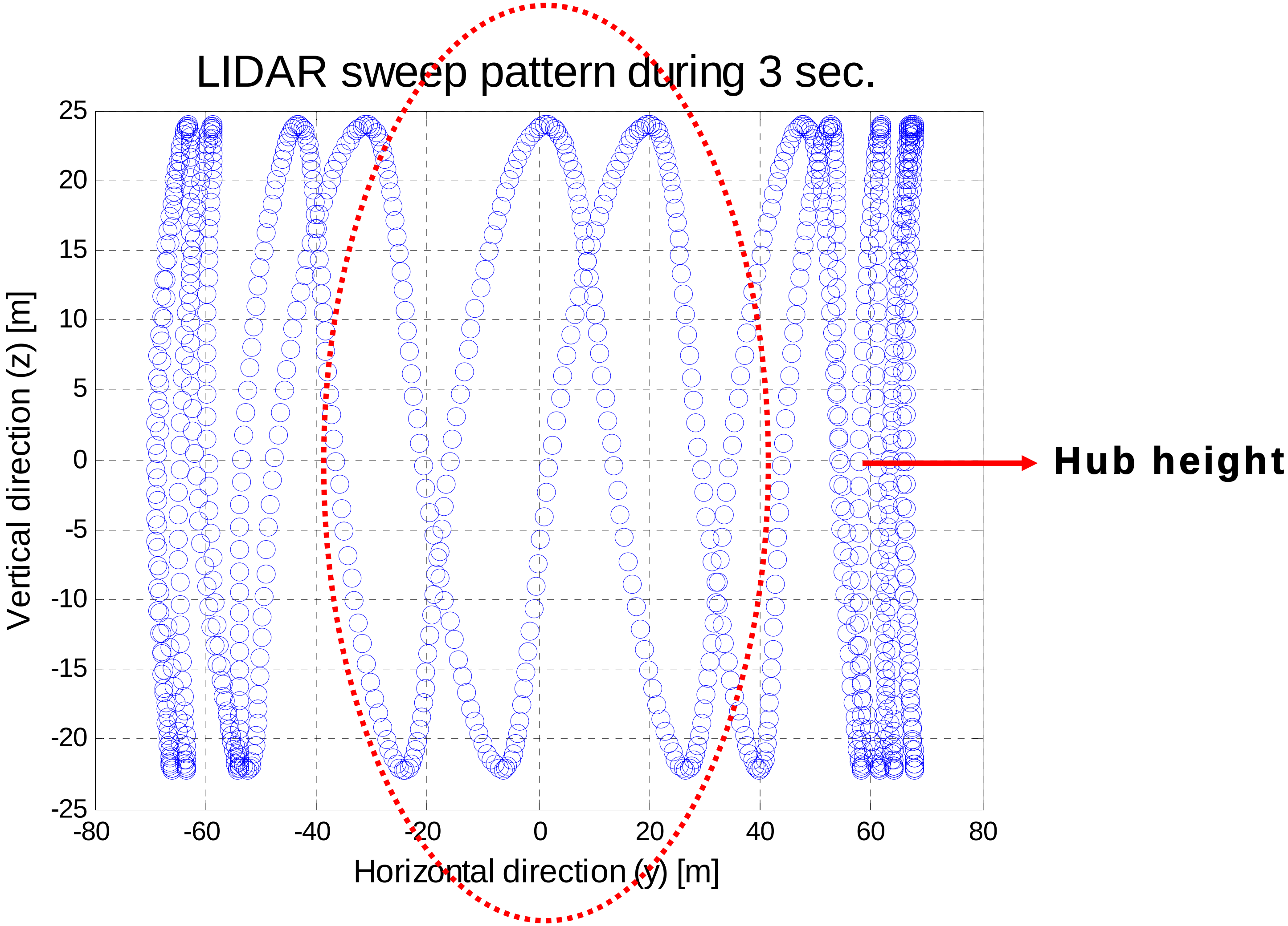
- PAN (horizontal) angle: ± 25º
- TILT (vertical) angle: ± 11º
- Scanning capacity (time resolution): 349 Hz
- Scanning capacity (spatial resolution): 1047 positions/plane (i.e. pr. 3 seconds)
- Focus limit maximum: 200m (= 2.5 x D)

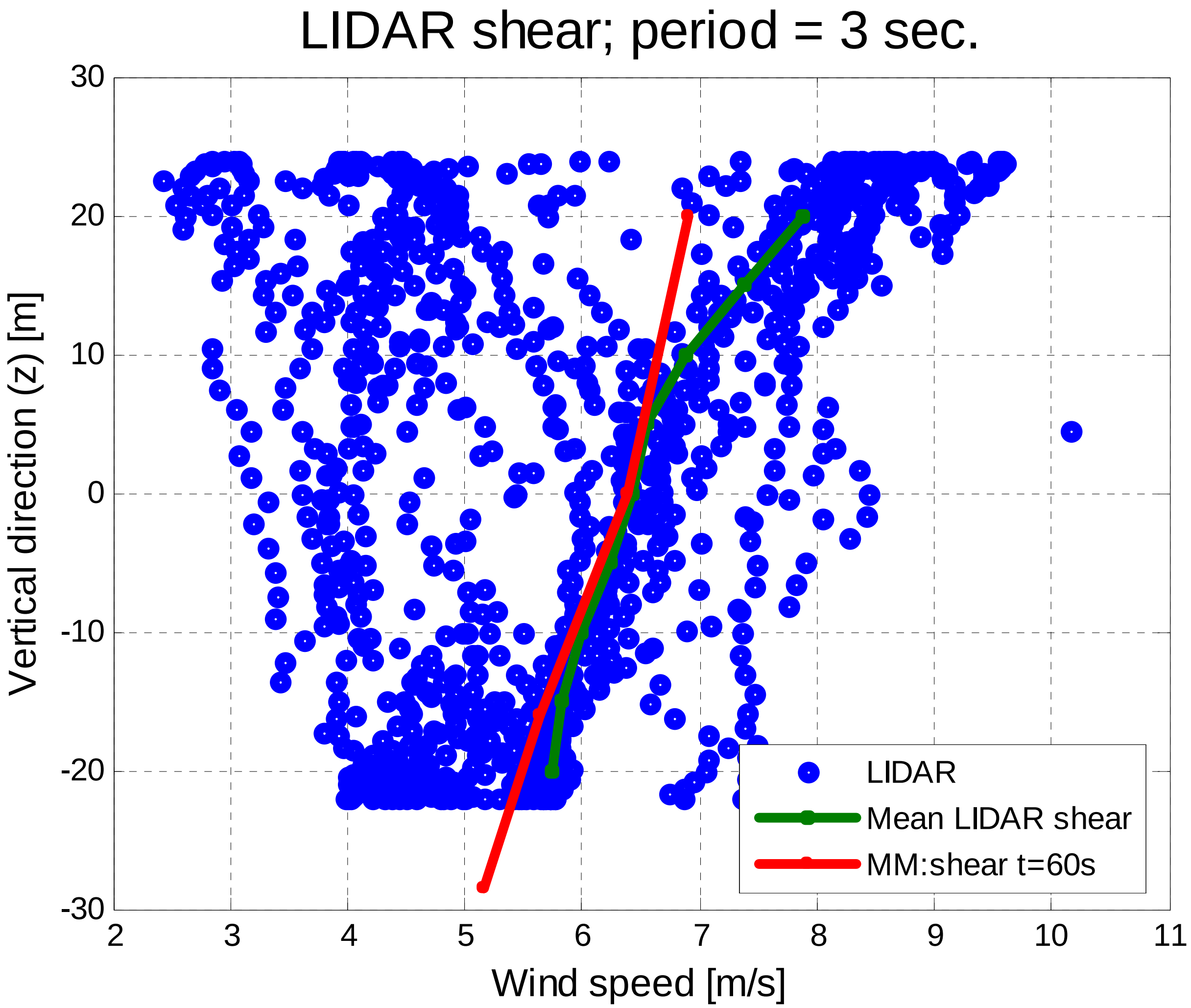
LiDAR mode options:

1) Constant focus distance (40, 80, 120, <u>160</u> or 200m)

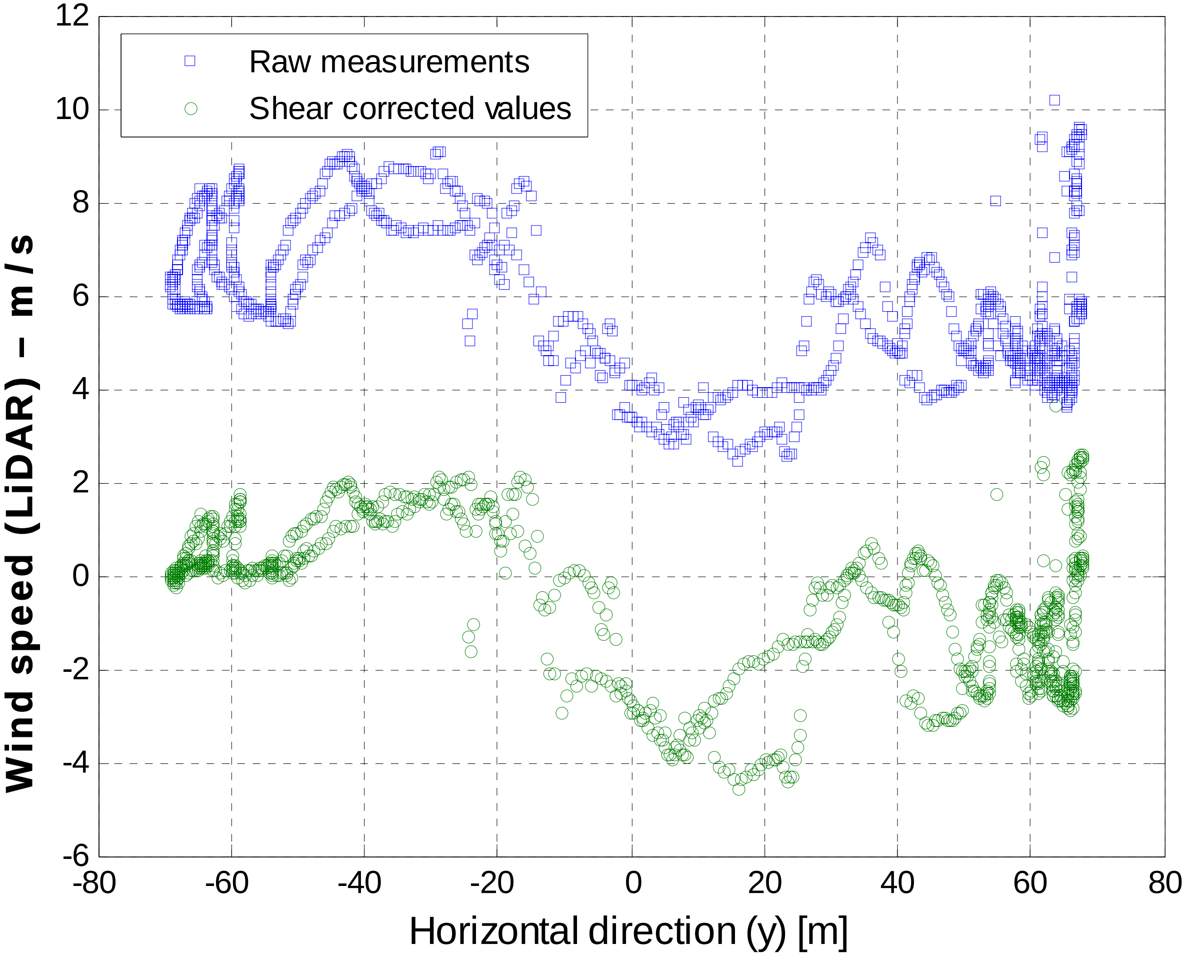
Preliminary measurements

- Measurement period: 1 – 15 February 2009.
- Measurements covers periods with moderate wind speeds and different flow direction.
- Low temperature operation (-10ºC – 0ºC).
- Wet and cloudy weather has reduced the data quality.
- Measurements includes single and double wake situations.
- Low wind speed measurements with mast in wake sector might be used for calibration?
- LiDAR is operating continuously during the next 2 months.


LIDAR sweep pattern during 3 sec.
Vertical direction (z) [m]
Horizontal direction (y) [m]
25
20
15
10
5
0
-5
-10
-15
-20
-25
-80
-60
-40
-20
0
20
40
60
80
Hub height


LIDAR shear; period = 3 sec.
Vertical direction (z) [m]
Wind speed [m/s]
30
20
10
0
-10
-20
-30
2
3
4
5
6
7
8
9
10
11
LIDAR
Mean LIDAR shear
MM:shear t=60s

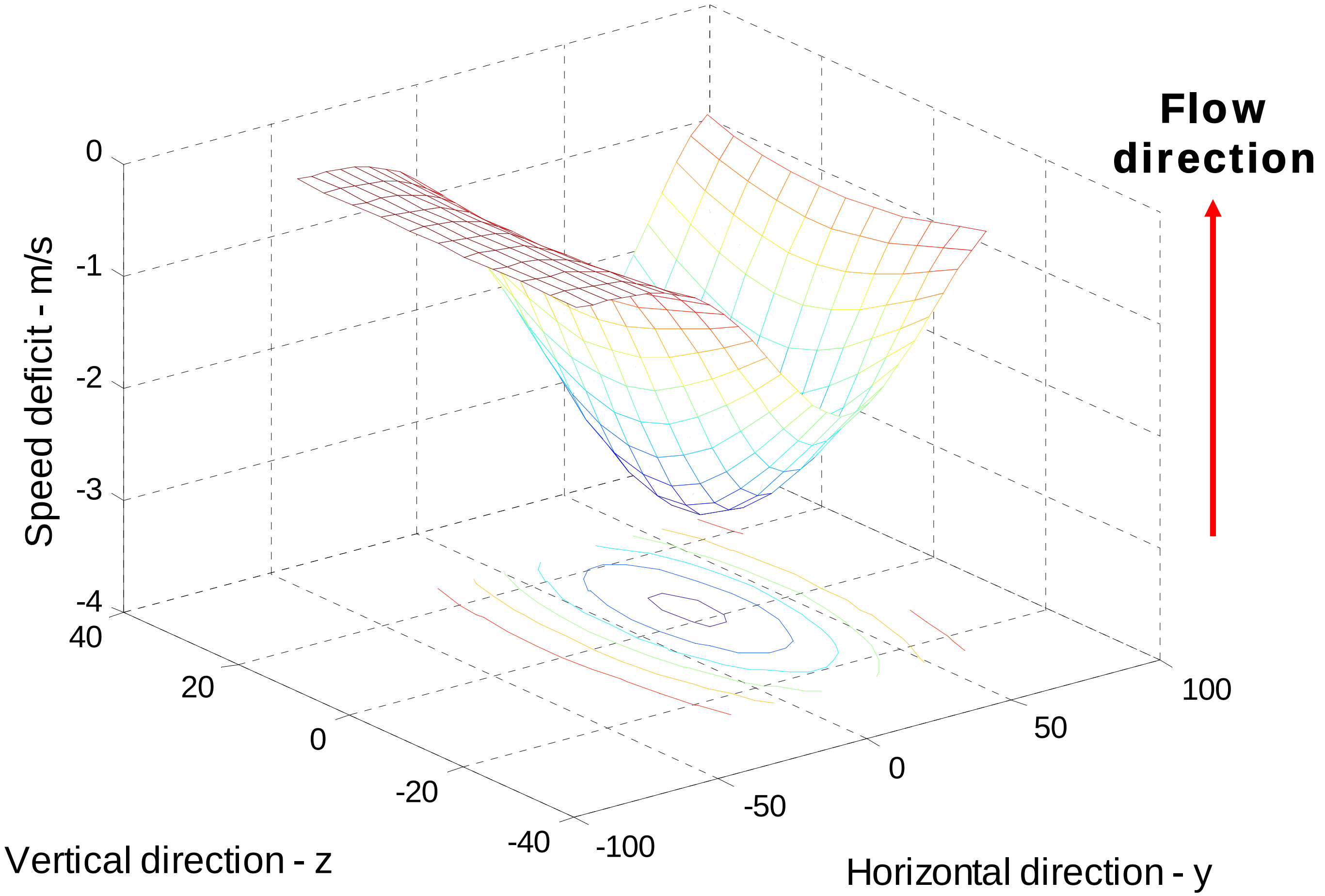
LIDAR speed measurements; period = 3 sec.

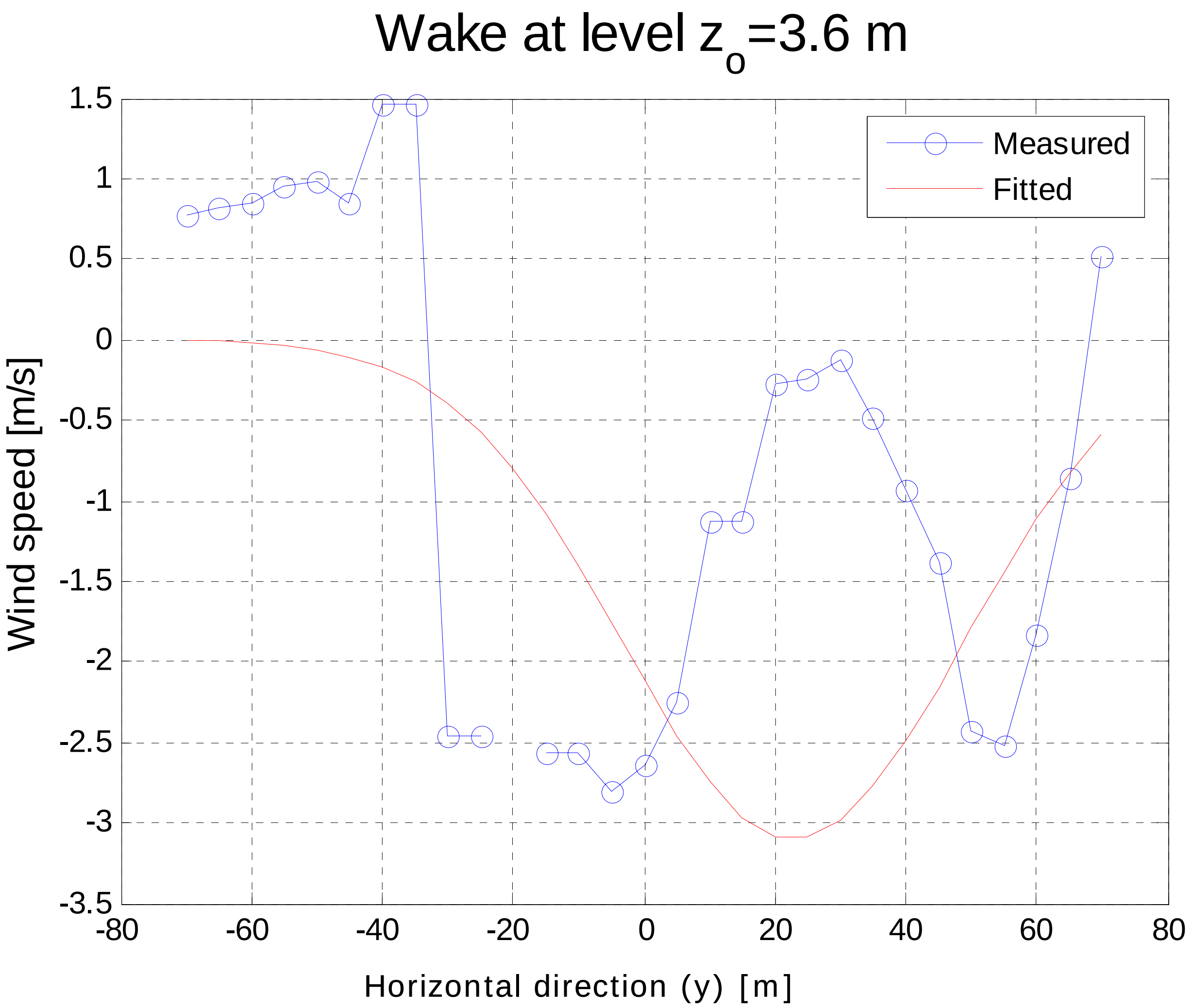


Wake position identification based on a bivariate Gaussian least square fit method

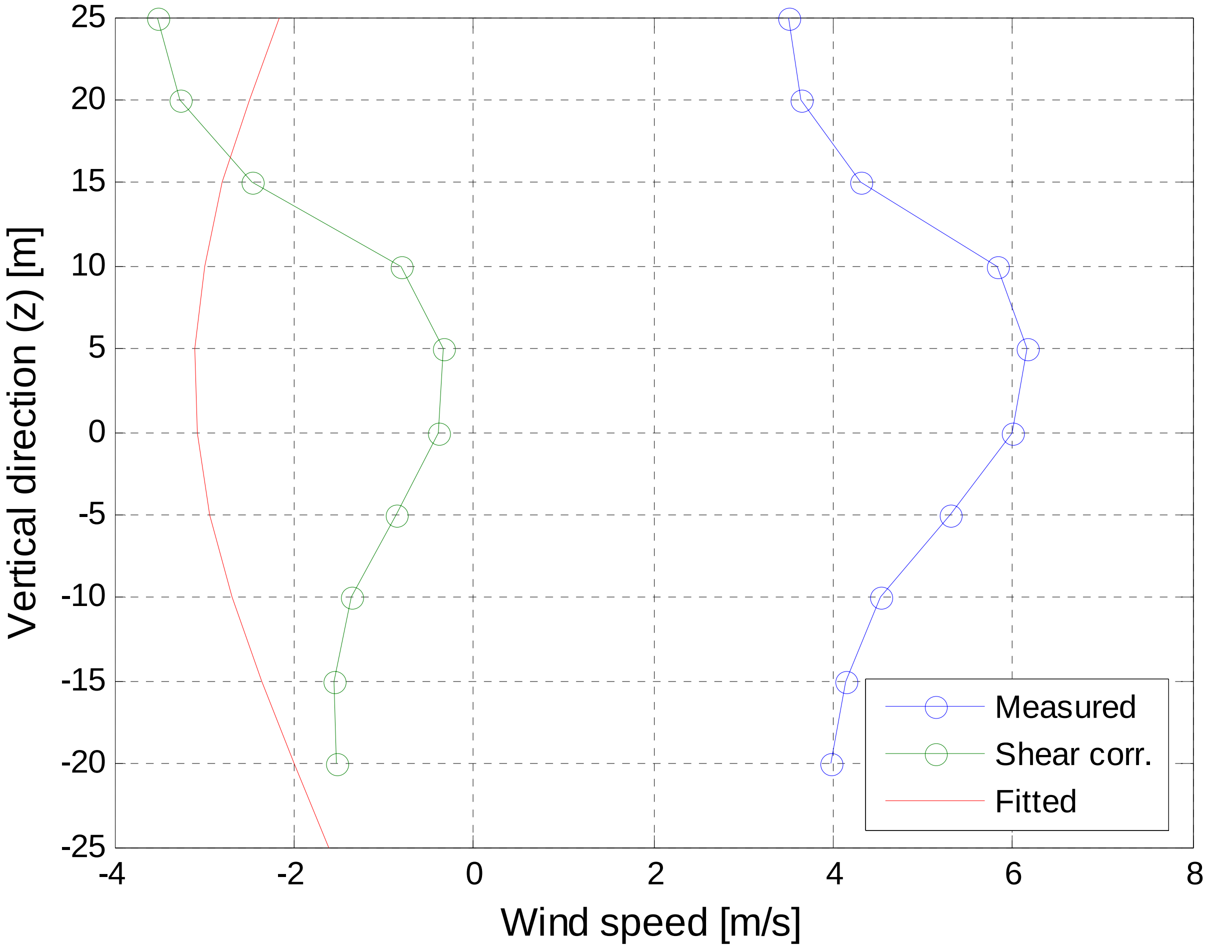
$$f(A,\mu_y,\mu_z,\sigma_y,\sigma_z) = \frac{A}{2\pi\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\times\left(\left(\frac{(y_i-\mu_y)^2}{\sigma_y{}^2}\right)+\left(\frac{(z_i-\mu_z)^2}{\sigma_z{}^2}\right)\right)\right]$$

Fitted speed deficit; ts=3 sec.

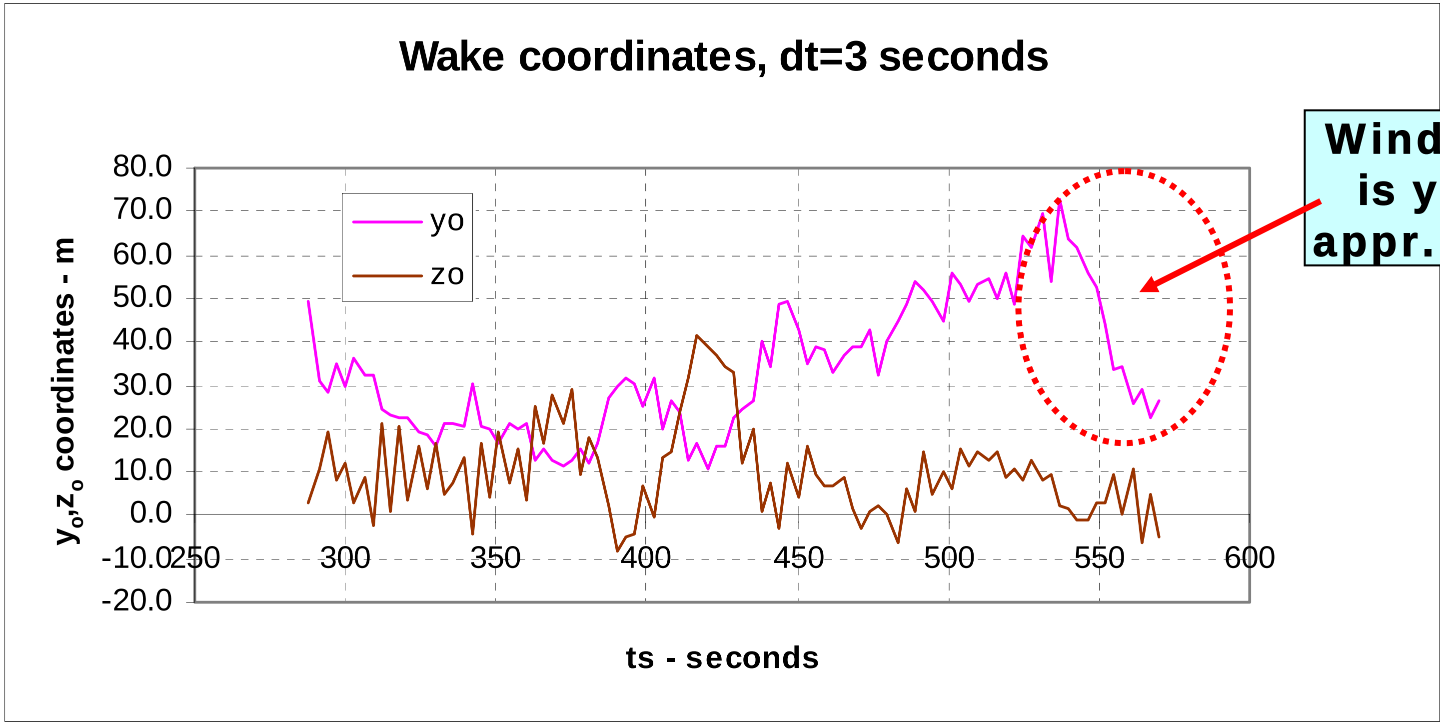



Wake at level z_o=3.6 m
Measured
Fitted
Wind speed [m/s]
Horizontal direction (y) [m]
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-80
-60
-40
-20
0
20
40
60
80

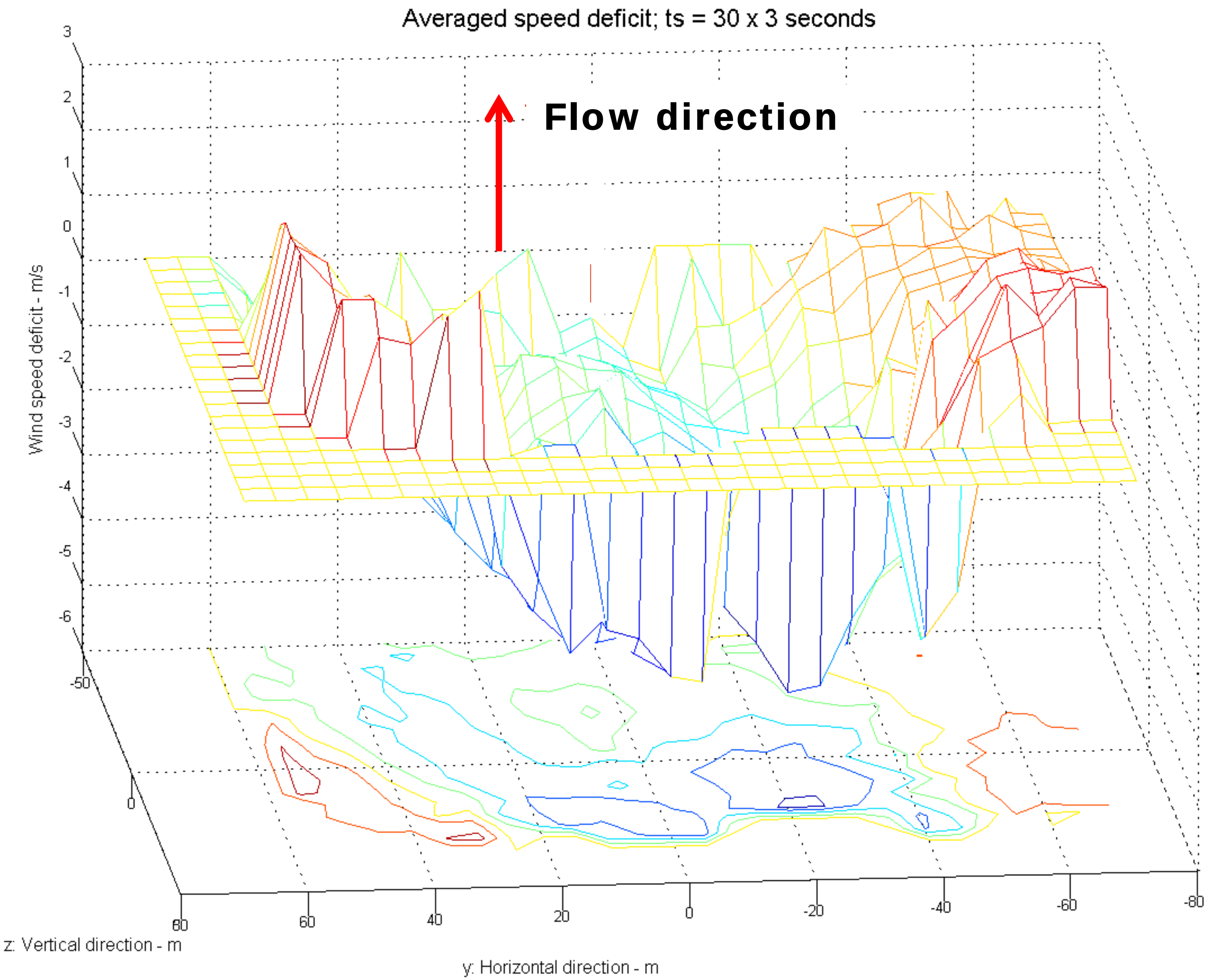
Wake at Pan position; y_o = 23 m



Wake (meandering) tracking

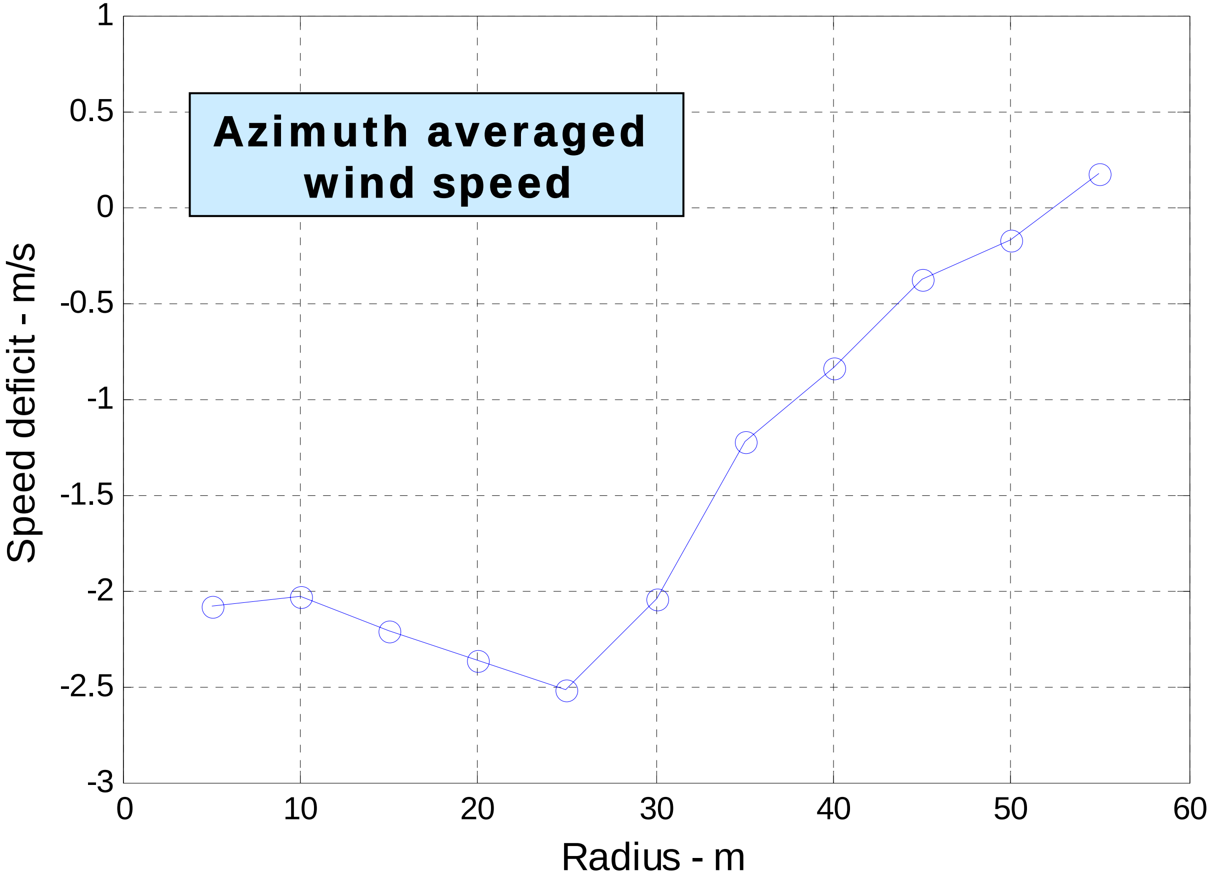


Wind turbine is yawing appr. 11 deg.

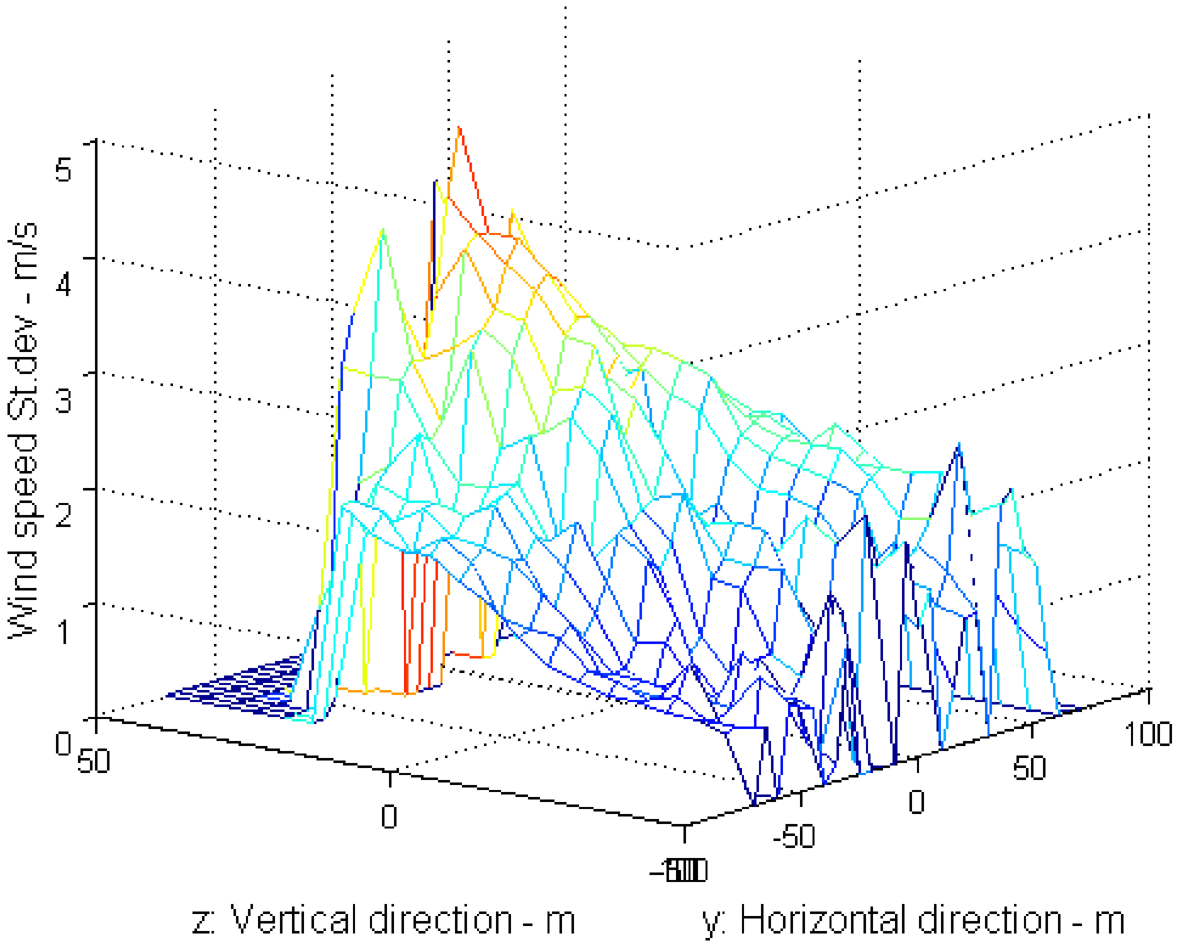


Averaged speed deficit; ts = 30 x 3 seconds
Flow direction
Wind speed deficit - m/s
3
2
1
0
-1
-2
-3
-4
-5
-6
-50
0
80
60
40
20
0
-20
-40
-60
-80
z: Vertical direction - m
y: Horizontal direction - m

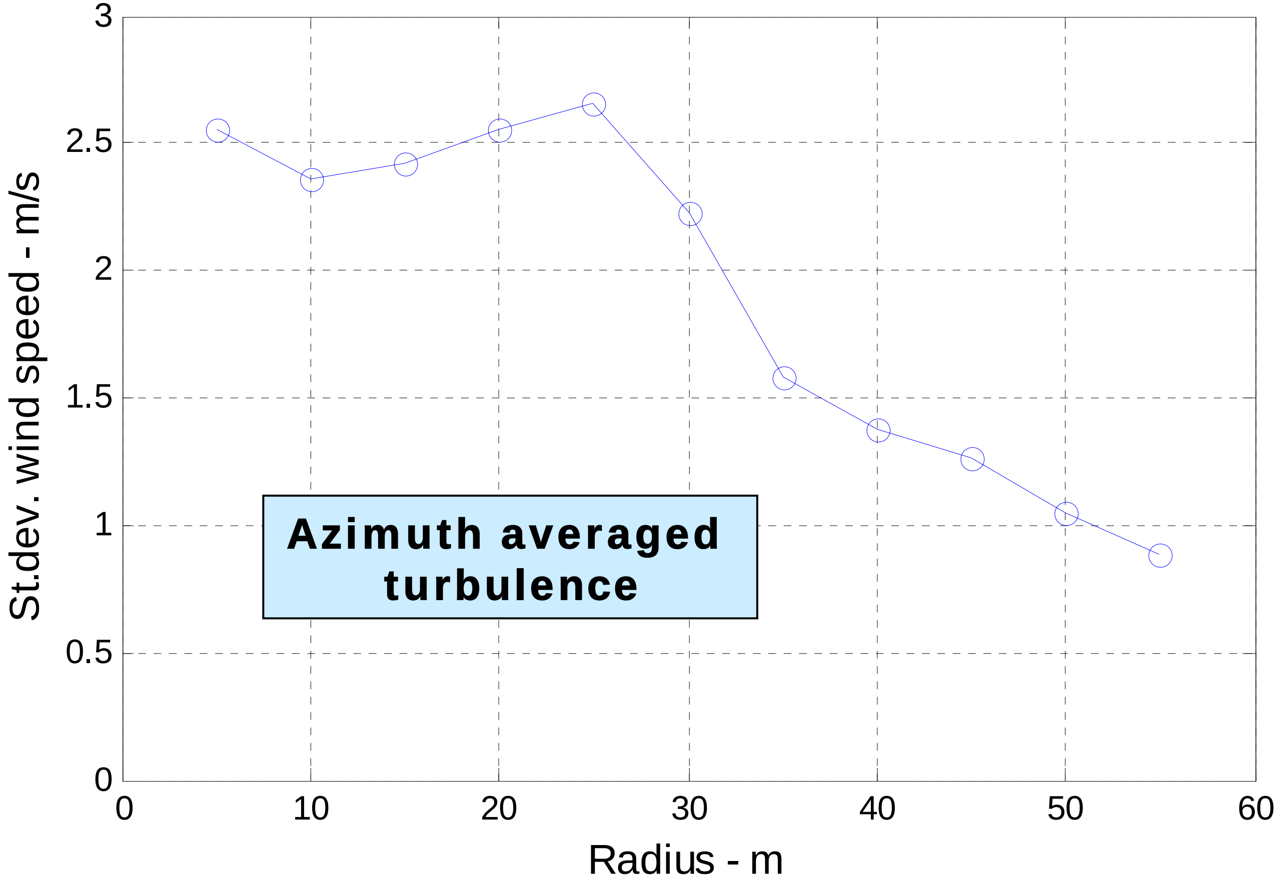
Radial speeds using aligned wakes, ts= 30 x 3 sec.



Average turbulence; ts = 30 x 3 seconds



Radial distribution of turbulence based on aligned wakes, ts=3 x 30 sec.



Time schedule for the wake measurements

- January– February 2009 : Initial measurements.
- March – April 2009: Continuously wake measurements

- Spring 2009: Campaign measurement with experimental blade;
  1) Measure flow conditions in the rotor plane with 5 hole pitot tubes.
  2) Measure wake speed deficits and turbulence.

Conclusion

- The wake meandering dynamics has been resolved
- The wake deficit has been resolved in the meandering frame of reference
- The inhomogeneous wake turbulence intensity characteristics has been resolved in the meandering frame of reference

Acknowledgements

- **EU project TOPFARM -** NEXT GENERATION DESIGN TOOL FOR OPTIMISATION OF WIND FARM TOPOLOGY AND OPERATION. Contract no. TREN07/FP6EN/S07.73680/038641.

- DONG Energy.

- VESTAS Wind Systems A/S.

Announcement

A EUROMECH colloquium will be organized 20–22 October 2009 in Madrid within the framework of TOPFARM. The theme for EUROMECH colloquium 508 is “Wind Turbine Wakes”.