Wake detection in the turbine inflow using nacelle lidars

Dominique P Held[1,2]
Nikolaos Kouris[2]
Antoine Larvol[2]
Jakob Mann[1]

Wind Energy Denmark 2018
30 – 31 October
Hedensted, Danmark

(1) Department of Wind Energy, Danish Technical University (DTU)
Frederiksborgvej 399, 4000 Roskilde, Denmark
(2) Windar Photonics A/S, Helgeshøj Alle 16-18, 2630 Taastrup, Denmark

Correspondence: domhel@dtu.dk

DTU Wind Energy
Department of Wind Energy

Table of Contents

Introduction

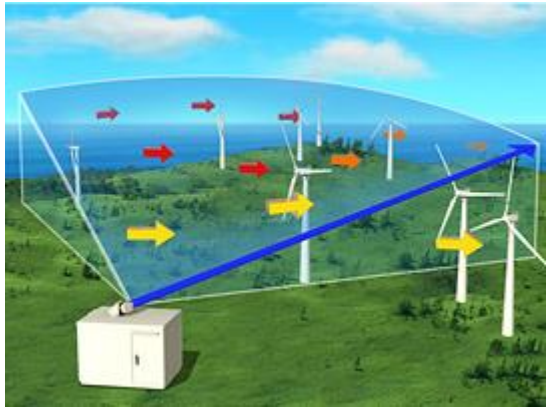
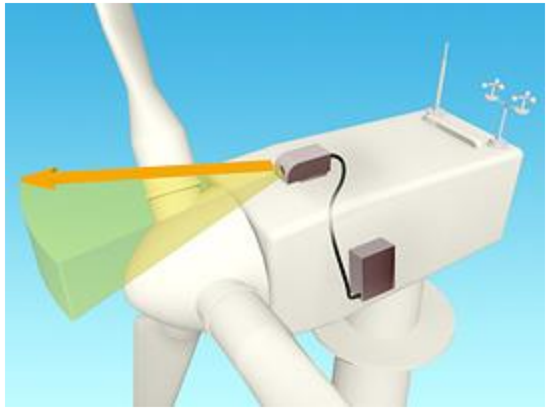
- Remote sensing allows for novel measurement strategies
  - Wide range of applications are possible

- Nacelle lidar systems allow remote sensing of turbine inflows

- Nacelle lidar potential:
  - Power curve validation
  - Control integration

→However new challenges arise with new sensors

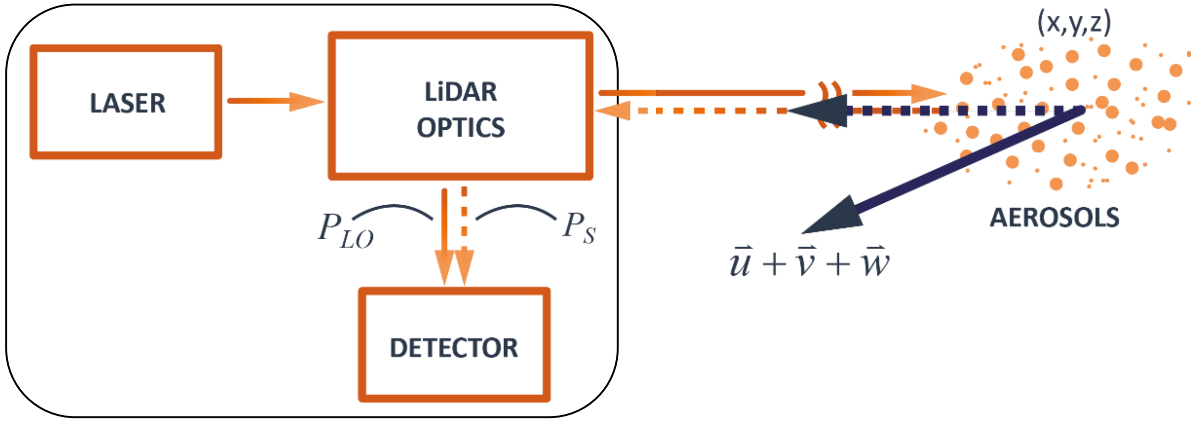


Illustrations by Mitsubishi Electric: http://www.mitsubishielectric.com/bu/lidar/lidar/applications/apps_01.html (Last accessed on 2018-09-10)

Measuring Inflow with Nacelle Lidars

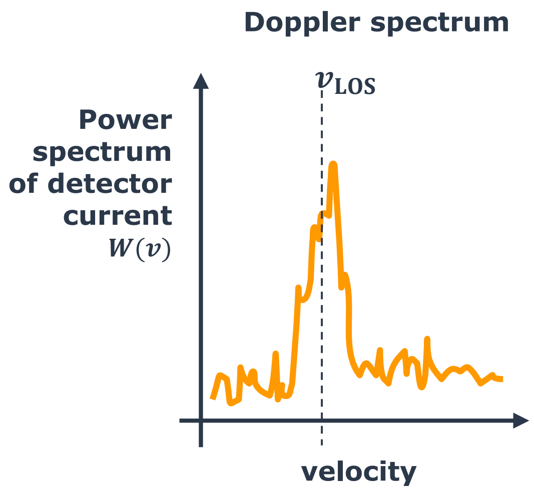
- Use of Optical Doppler effect
- Frequency shift in backscattered light is proportional to aerosol movement



- Coherent detection using a CW laser
  - Analysis of the Doppler spectrum

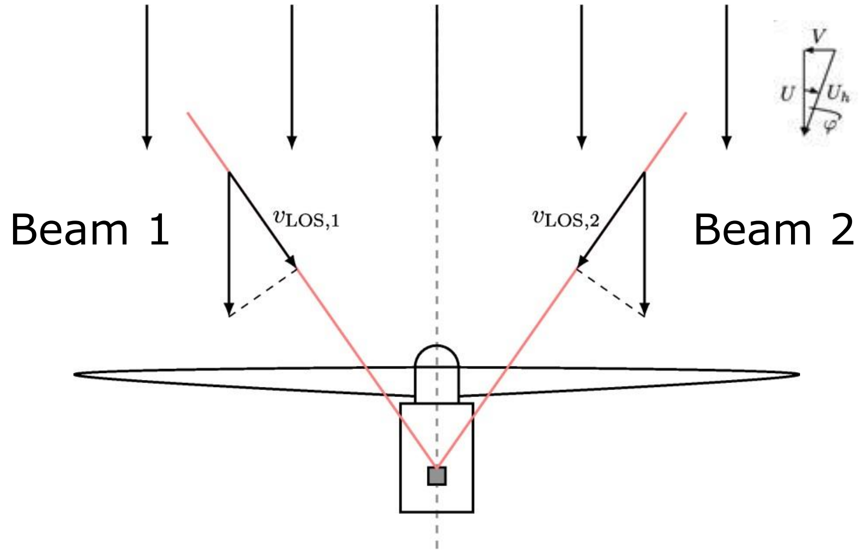
Important measurement differences compared to cup or sonic anemometers:

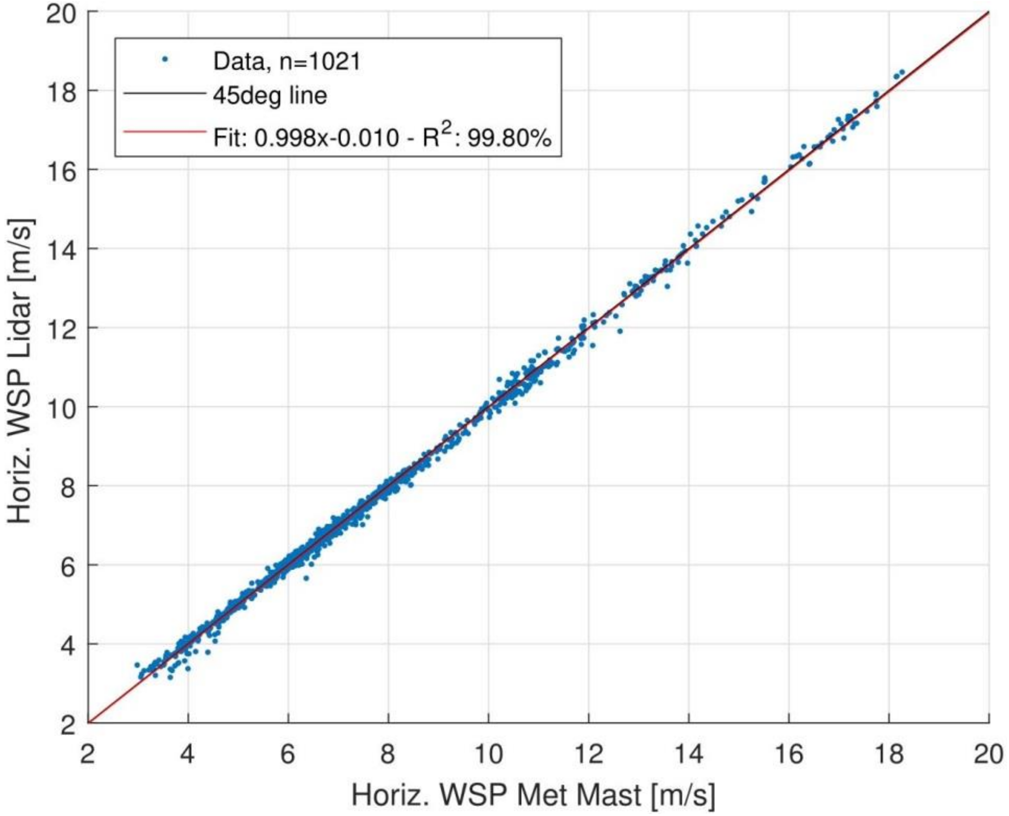
- ➢ Volume measurement → Low-pass filter effect
- ➢ Measurement of line-of-sight (LOS) component



Measuring Inflow Characteristics

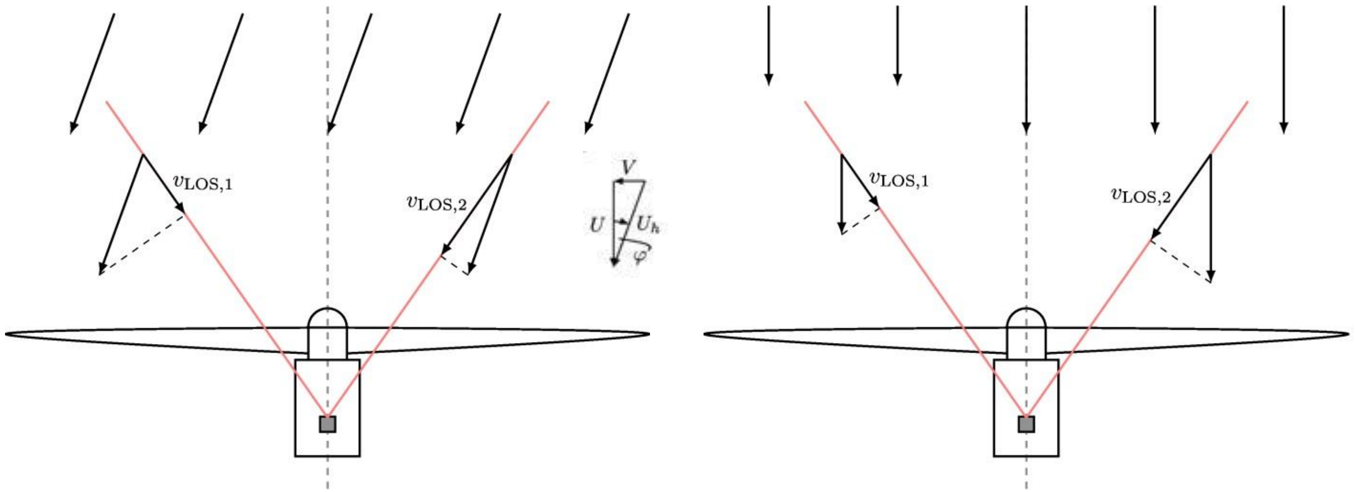
- Assumptions of wind field are necessary due to limitation to radial wind speeds
- Horizontal homogeneity is used by nacelle lidars (and many other lidar systems)



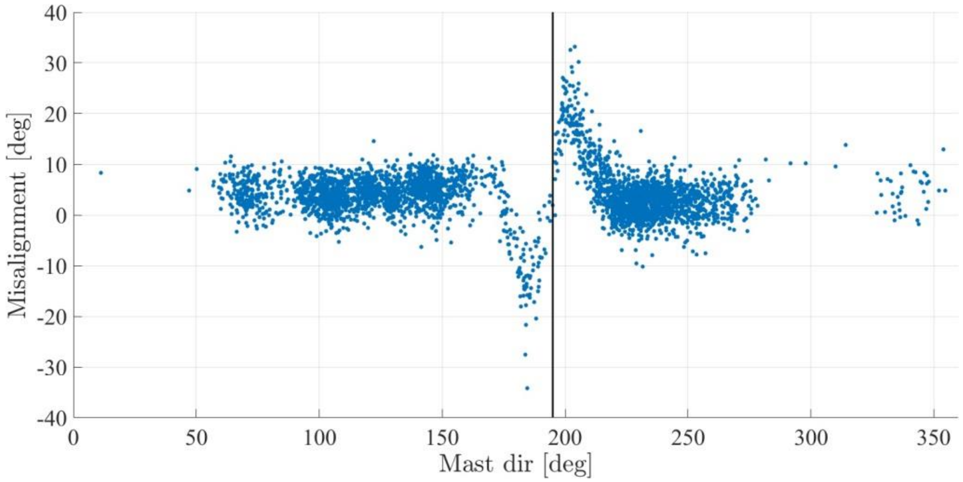


Motivation

- Assumptions of wind field are necessary due to limitation to radial wind speeds
- Horizontal homogeneity is used by nacelle lidars (and many other lidar systems)
  - ➢ Problems arise when the flow violates assumptions



Influence has been tested at DTU’s Risø test site in a 1-month long experiment



Wake Detection - Methodology

1. Wakes create turbulence with a much smaller length scale than ambient flows[1]

2. Small-scale turbulence is filtered by the lidar system due to large probe volume
   → attenuated turbulence widens the Doppler spectrum

By comparing Doppler spectral widths, the increased small-scale turbulence inside a wake can be detected.

$$\mathrm{TI}_{\mathrm{LOS}} = \frac{\sigma_{\mathrm{LOS}}}{v_{\mathrm{LOS}}} \qquad {\sigma_{\mathrm{LOS}}}^2 = \frac{\int (v - v_{\mathrm{LOS}})^2 W(v) dv}{\int W(v) dv}$$

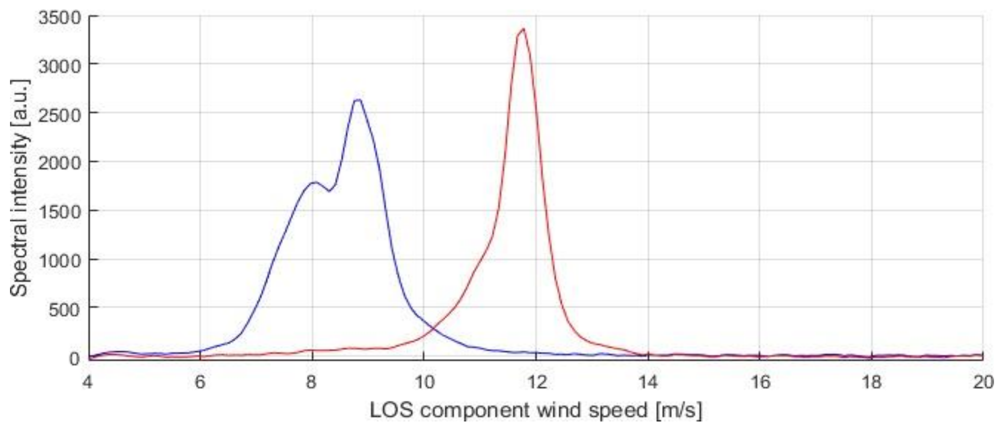
$$\Delta TI_{LOS} = \mathrm{TI}_{\mathrm{LOS},1} - \mathrm{TI}_{\mathrm{LOS},2}$$

${\sigma_{\mathrm{LOS}}}^2$: Doppler peak variance [m²/s²]

v_{LOS} : radial speed measurement [m/s]

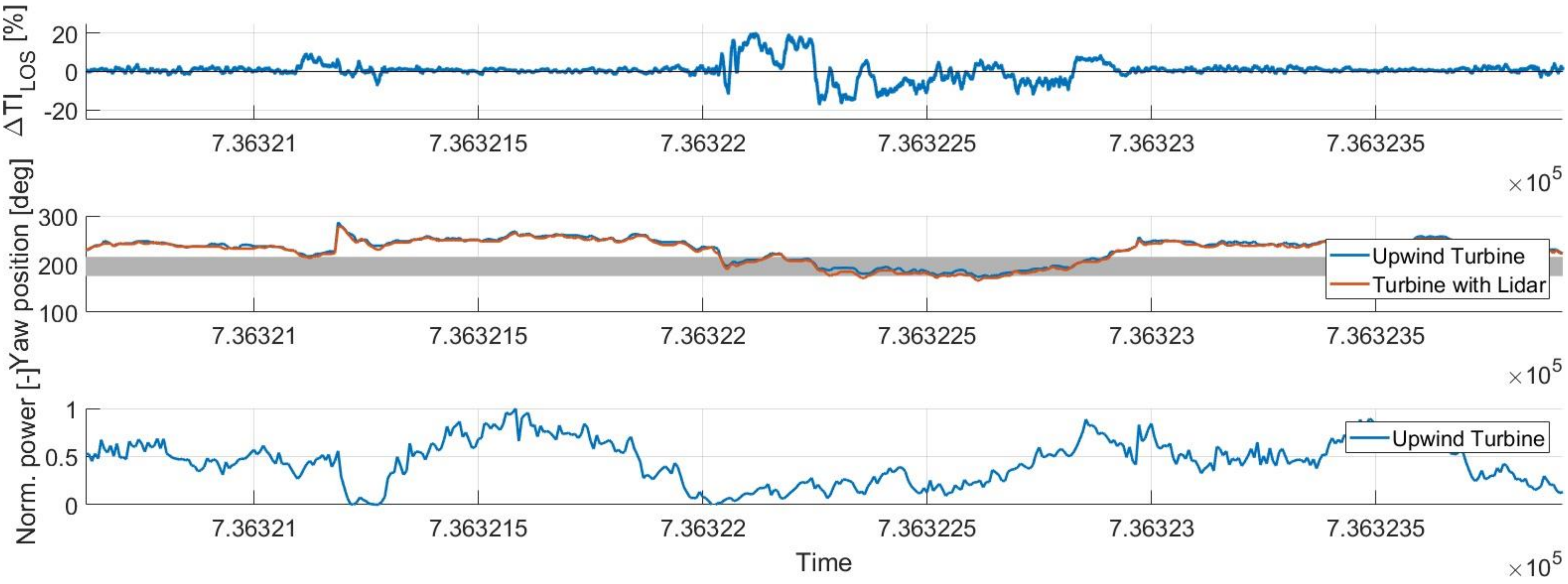
$W(v)$: lidar Doppler spectrum

5 seconds average spectra

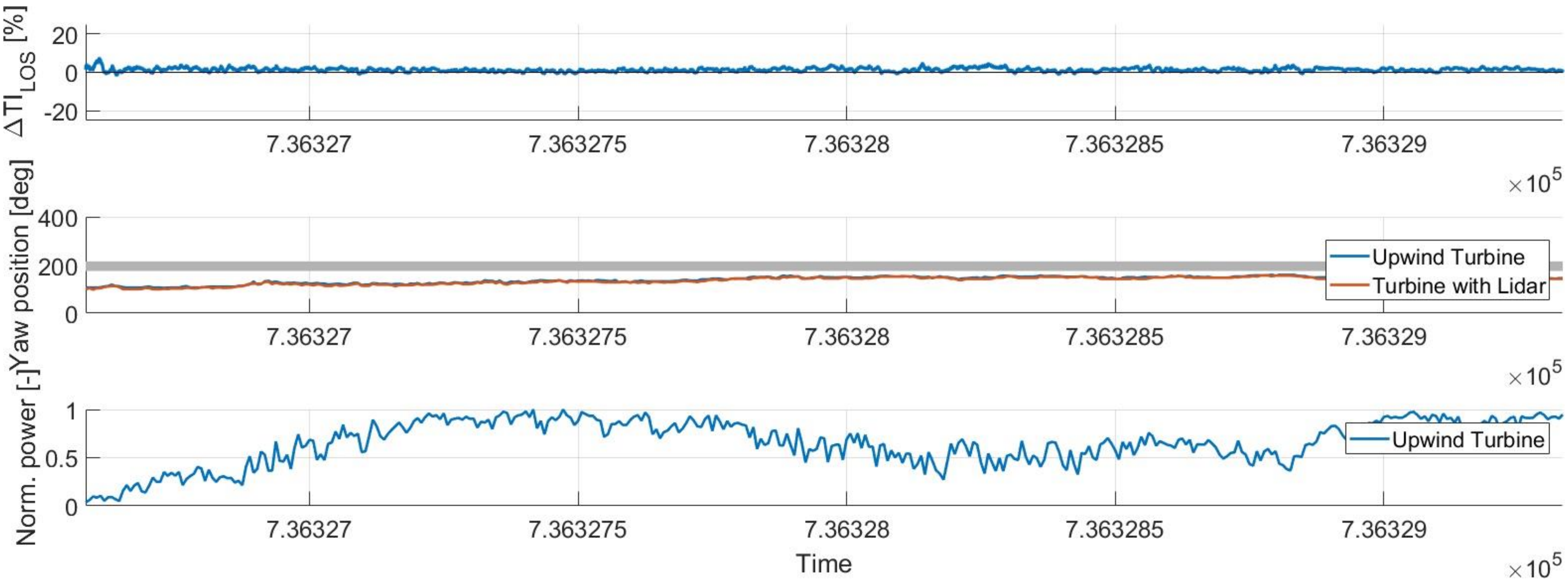


1 G. C. Larsen, K. S. Hansen, J. Mann, K. Enevoldsen and F. Bingöl, "Full scale measurements of wind turbine wake turbulence," in *The Science of Making Torque from Wind*, Heraklion, Greece, 2010.

Wake Detection - Results

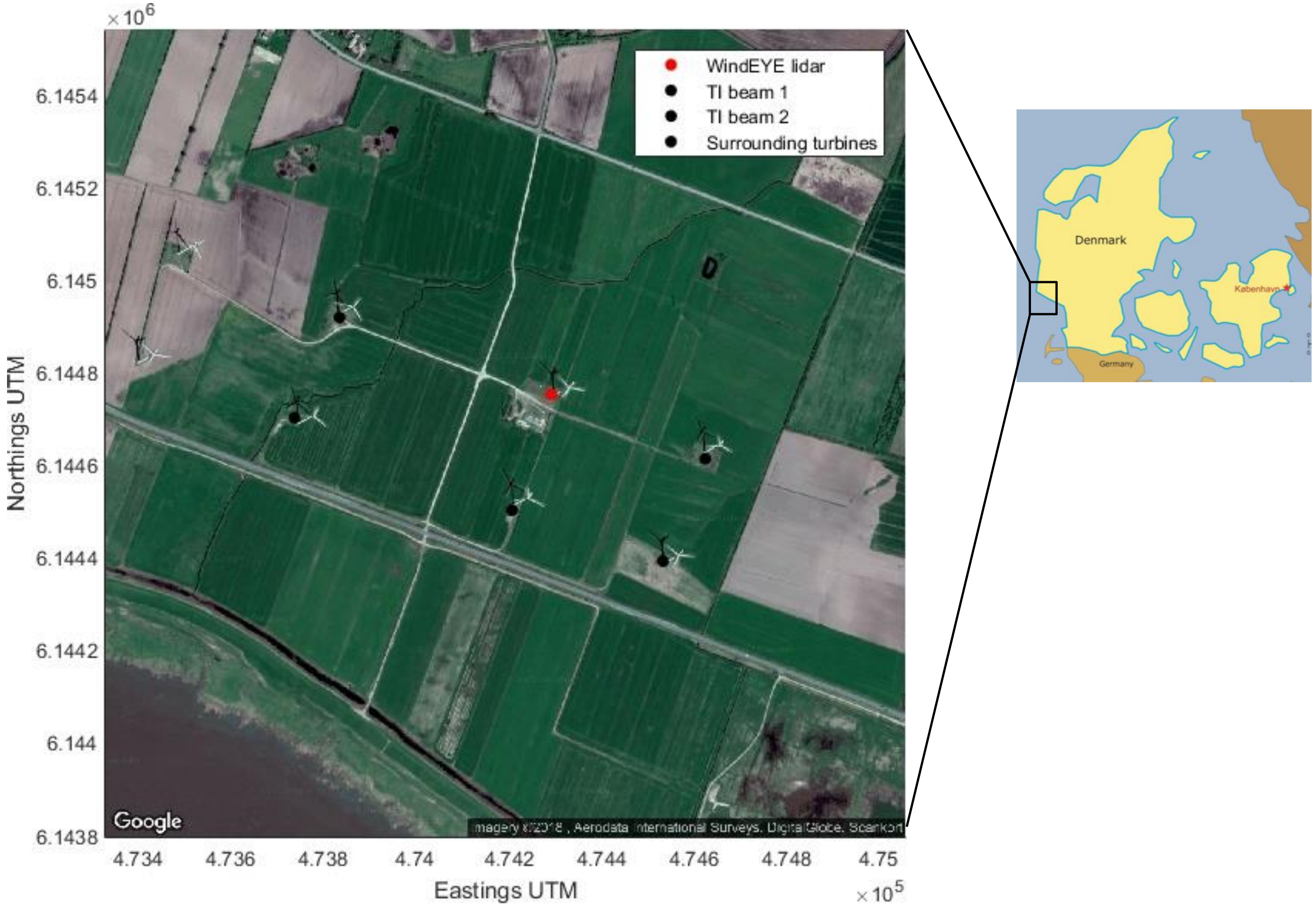


Wake Detection - Results



Site Setup

- 8x 2.75 MW turbines in Western Denmark
- 1 turbine equipped with Windar Photonics lidar
- Turbine spacing: 250m (≈3D) – 560m (≈7D)
  - Here 5 closest turbines are considered
- Measurements between Nov 2014 and Mar 2015



Wake Detection - Results

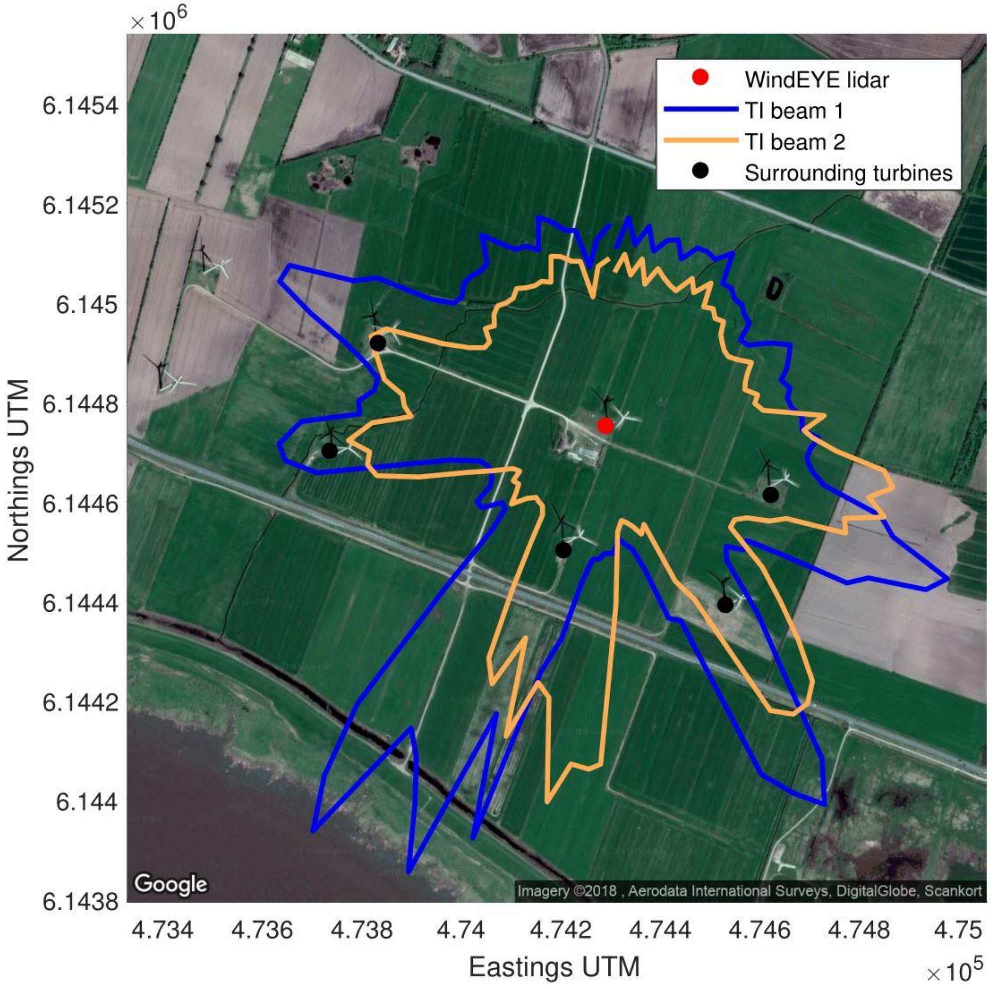
- Detection algorithm uses LOS turbulence intensity

$$\mathrm{TI_{LOS}} = \frac{\sigma_{\mathrm{LOS}}}{v_{\mathrm{LOS}}}$$

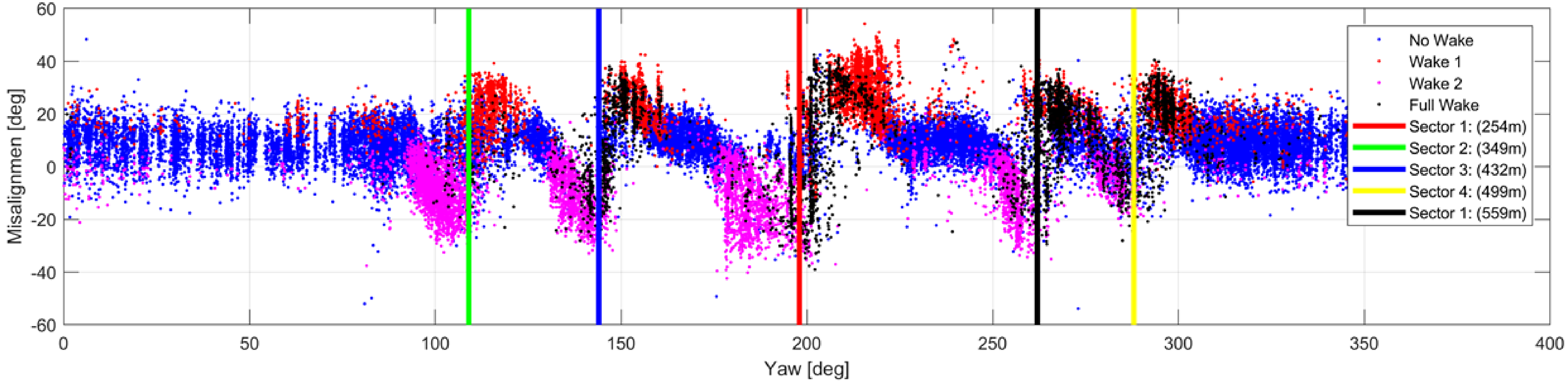
- Turbine mean misalignment leads to lower v_{LOS} for beam 1
  → higher $\mathrm{TI_{LOS}}$ for beam 1

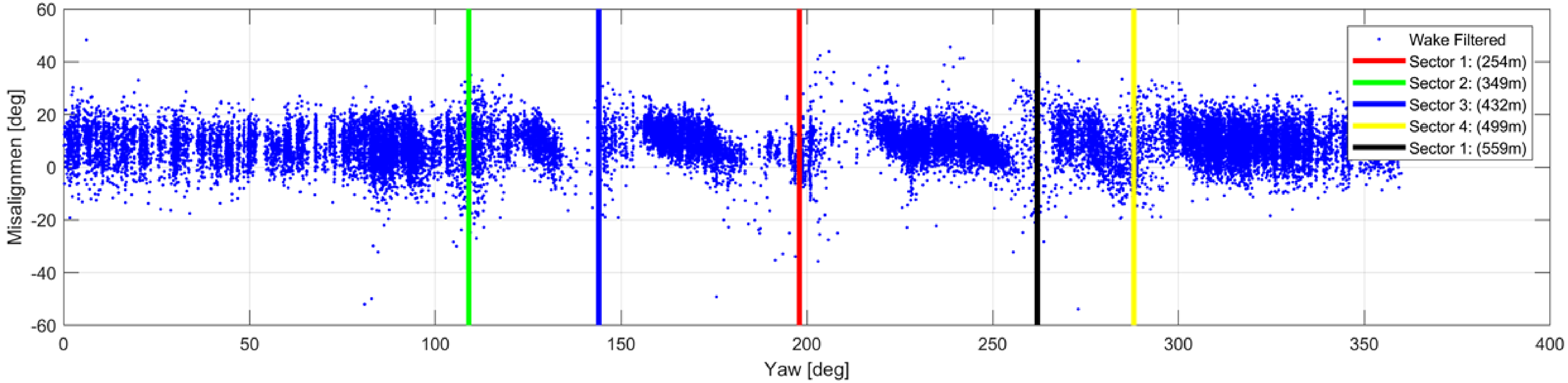
- Higher $\mathrm{LOS\ TI}$ when wake situation are expected

- Difference between beam 1 and 2
  → caused by half-wake situations



Wake Detection - Results





Conclusion

- By comparing spectral width at different positions wake detection in inflow is possible
- Detection results can be used for
  - Correcting misalignment measurements
  - Reducing loads by yawing downstream turbines
  - Maximizing wind farm power production through wake steering or turbine derating

- Future Work includes:
  - Testing in complex terrain
  - Further refinement of algorithm

For further question:

Email domhel@dtu.dk

Thank you for your attention!