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Lidar measurements of wind across a virtual rotor plane

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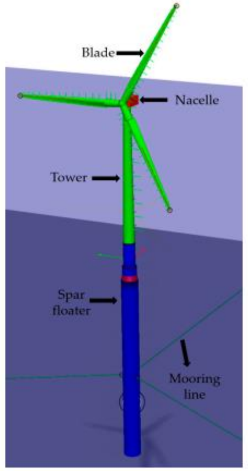
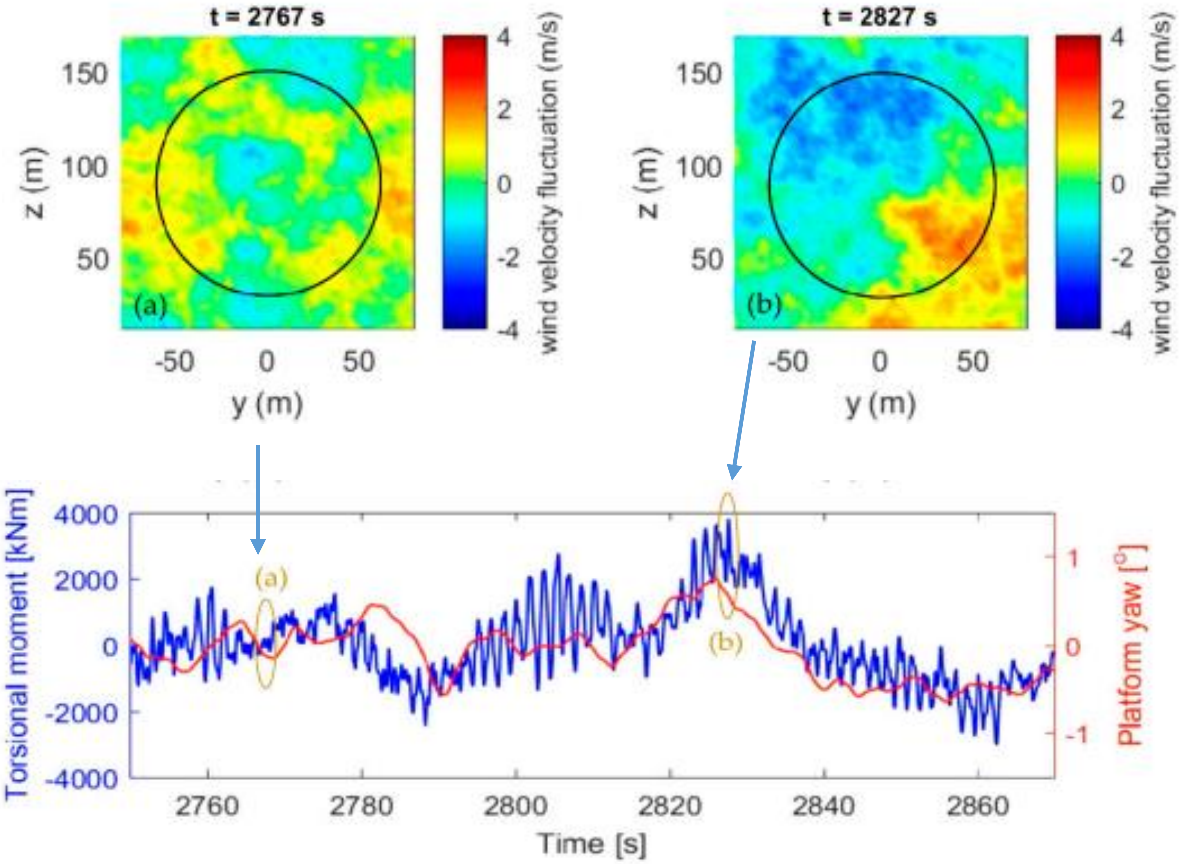
Outline

- Background
- Measurement site
- Measurement setup
- Data acquisition and pre-processing
- Data analysis and selected results:
- Mean flow characteristics
  - Turbulence characteristics
- Conclusions and further work

Background

- Wind velocity variations in time and space are relevant for design of wind turbines, especially large floating offshore turbines.
- Example: simulated OC3 Hywind spar wind turbine response (tower top twisting moment and platform yaw) follows an increase and decrease in turbulence synchronization across the rotor, U=15 m/s ([1]).





[1] Putri, R., Obhrai, C., Jakobsen, J.B., Ong, M.C. (2020) Numerical Analysis of the Effect of Offshore Turbulent Wind Inflow on the Response of a Spar Wind Turbine. Energies 13 (10)

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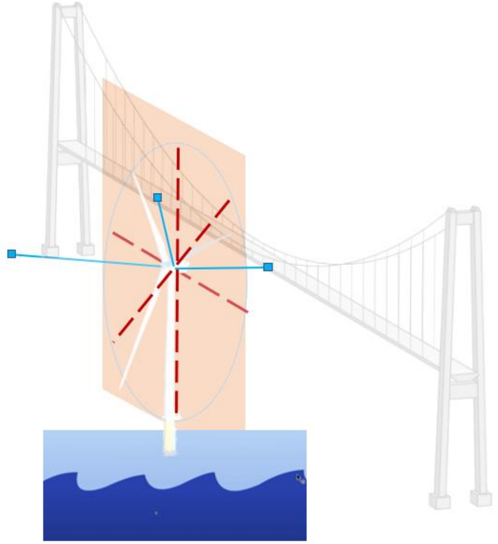
Field observations of wind coherence

- Lateral coherence of turbulence challenging to observe from an offshore measurement mast.

➢ Remote optical wind sensing offshore and near shore includes campaigns targeting coherence estimation, e.g. with:
  - Single pulsed scanning lidar on an offshore platform (Fino 1, [2])
  - Triple "parallel" scanning lidars from shore (Obrestad, [3]).

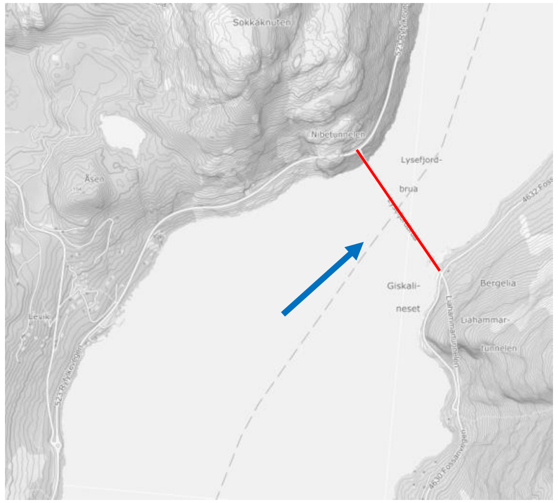
➢ Present work: triple lidar measurements of wind flow across a virtual rotor from a suspension bridge.



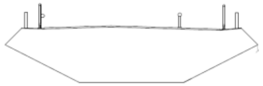
[2] Cheynet, E., Jakobsen, J.B., Svardal, B., Reuder, J., Kumer, V. (2016) Wind Coherence Measurement by a Single Pulsed Doppler Wind Lidar. Energy Procedia, 90: 462-477.

[3] Cheynet, E., Flügge, M., Reuder, J., Jakobsen, J.B., Heggelund, Y., Svardal, B., Saavedra Garfias, P.A., Obhrai, Ch., Daniotti, N., Berge, J., Duscha, Ch.A., Wildmann, N., Onarheim, I., Godvik, M. (2021) The COTUR project: Remote sensing of offshore turbulence for wind energy application. Atmospheric Measurement Techniques. 14 (9), 6137-6157.

Measurement site



www.norgeskart.no



L= 446 m, z= 55 m,
B= 12.3 m H= 2.76 m

Lysefjord bridge outdoor laboratory:

- Since 2013, extensively instrumented by sensors for turbulence and bridge vibrations monitoring.

Lidar measurement campaigns at the bridge site:

- Long-range lidar measurements from shore (2014).
- *Dual* continuous-wave lidar measurements from the bridge deck (2014):
  - Mean flow characteristics and coherence of incoming turbulence
  - Mean wind profile in the wake of the bridge deck
- Lidar measurement campaign with *triple* continuous-wave lidars on the bridge (2021).

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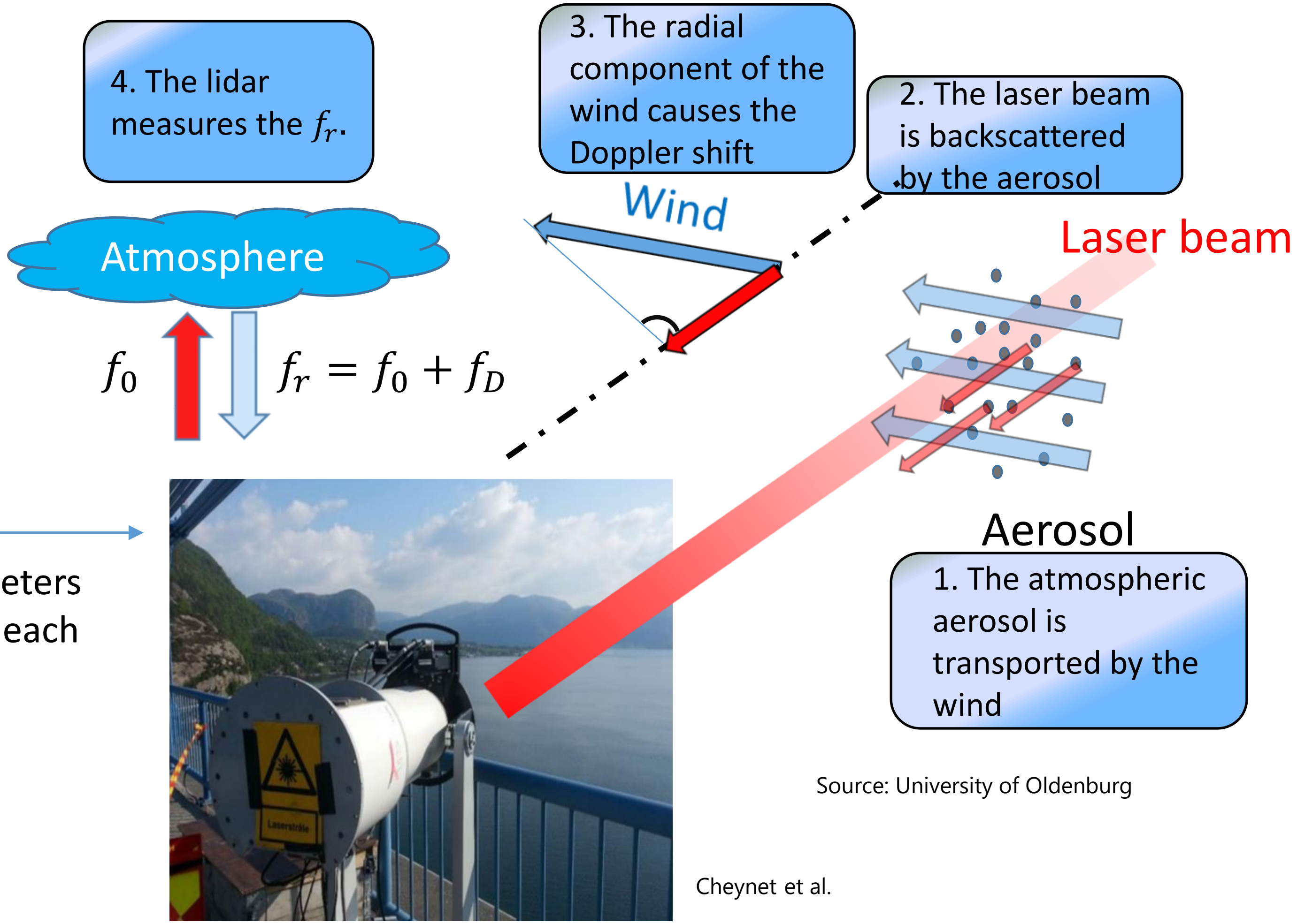
LiDAR measurement principle

A line-of-sight velocity (along a laser beam) v_{los} is obtained from a frequency difference f_D (so-called Doppler shift), between the emitted (f_0), and back scattered/received light wave (f_r):

$$f_r = f_0 + f_D \, , f_D = \frac{2v_{los}}{\lambda_0}$$

Continuous Wave lidar:

- Measures up to few hundred meters
- Single volume measurement at each time step



Source: University of Oldenburg

Cheynet et al.

Measurement setup design considerations

WindScanner system with three CW lidars (based on Zephir 150, 3’’telescopes) from DTU

- Location of lidars:
  - Ensure three lidar beams not co-planar
  - Limit the sampling volume
  - Terrain accessibility
  - Smaller distance between two deck lidars for flow mapping closer to the deck
  - Avoid proximity to the tower
- Measurement period: August – October 2021.





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Scanning patterns

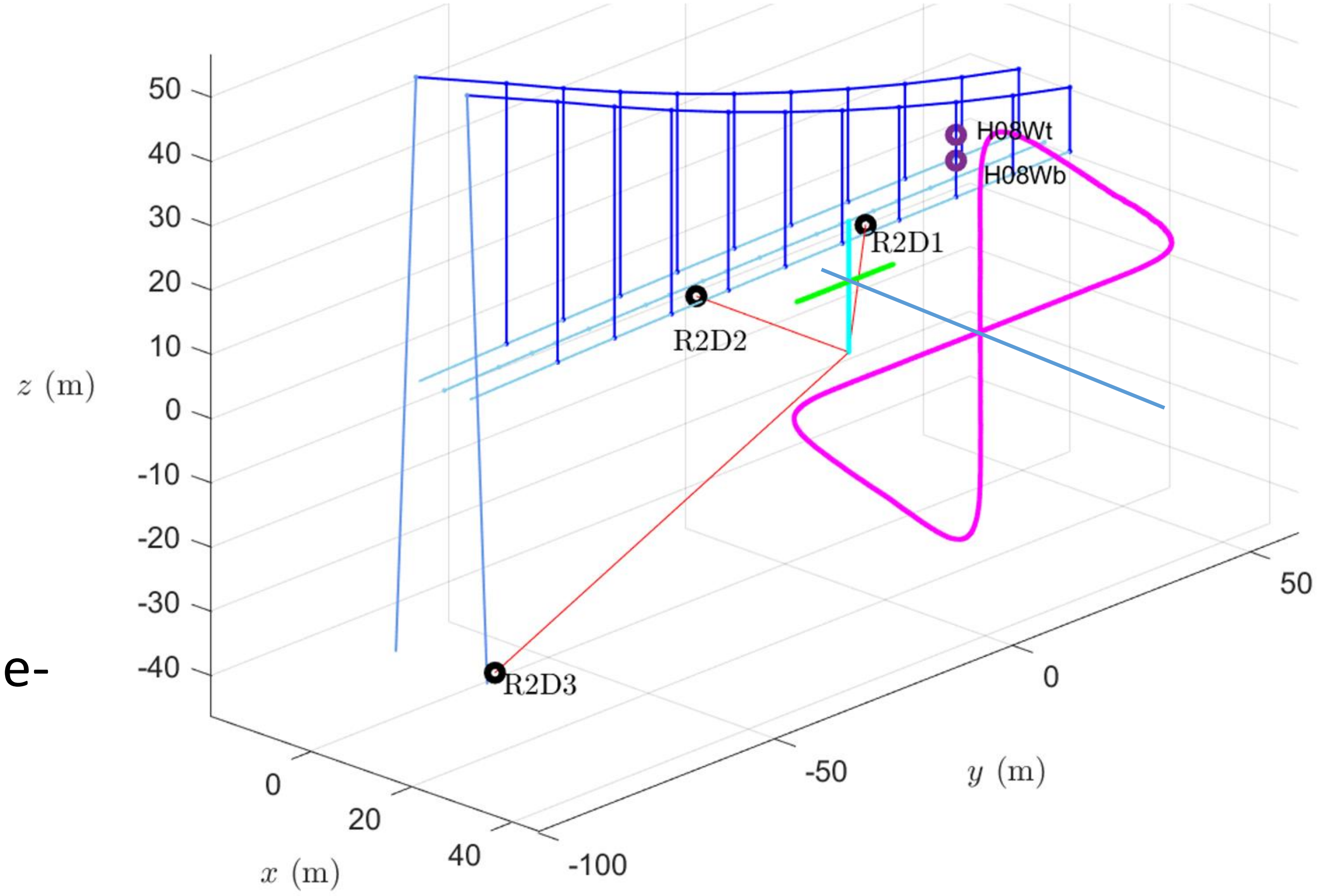
90 minutes long cycle

322.6 Hz sampling frequency:

- Bow pattern, f_s=1 Hz 30 min
- Vertical line, f_s=2 Hz 20 min
- Horisontal line, f_s=2 Hz 20 min
- Perpendicular line, f_s=1 Hz 20 min

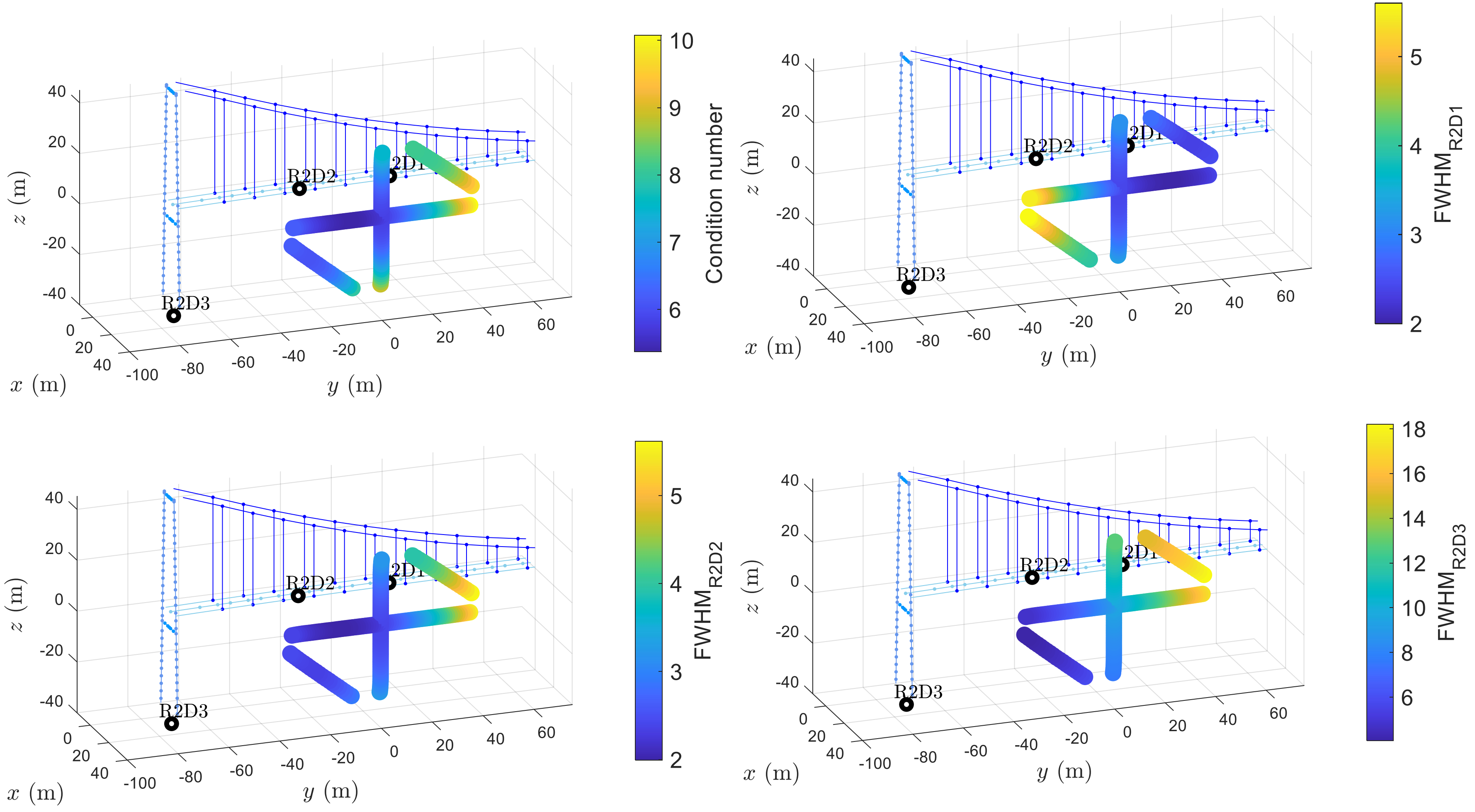
Data pre-processing:

- LOS velocity estimation
- Data interpolation to a fixed time-step
- Dynamic radial velocity vectors transformations



BowTie-like pattern

- CW lidar range resolution is expressed by its full width at half maximum (FWHM)
- FWHM increases quadratically with the measurement distance
- The sensitivity of the estimated velocity components is related to the condition number of the transformation matrix.

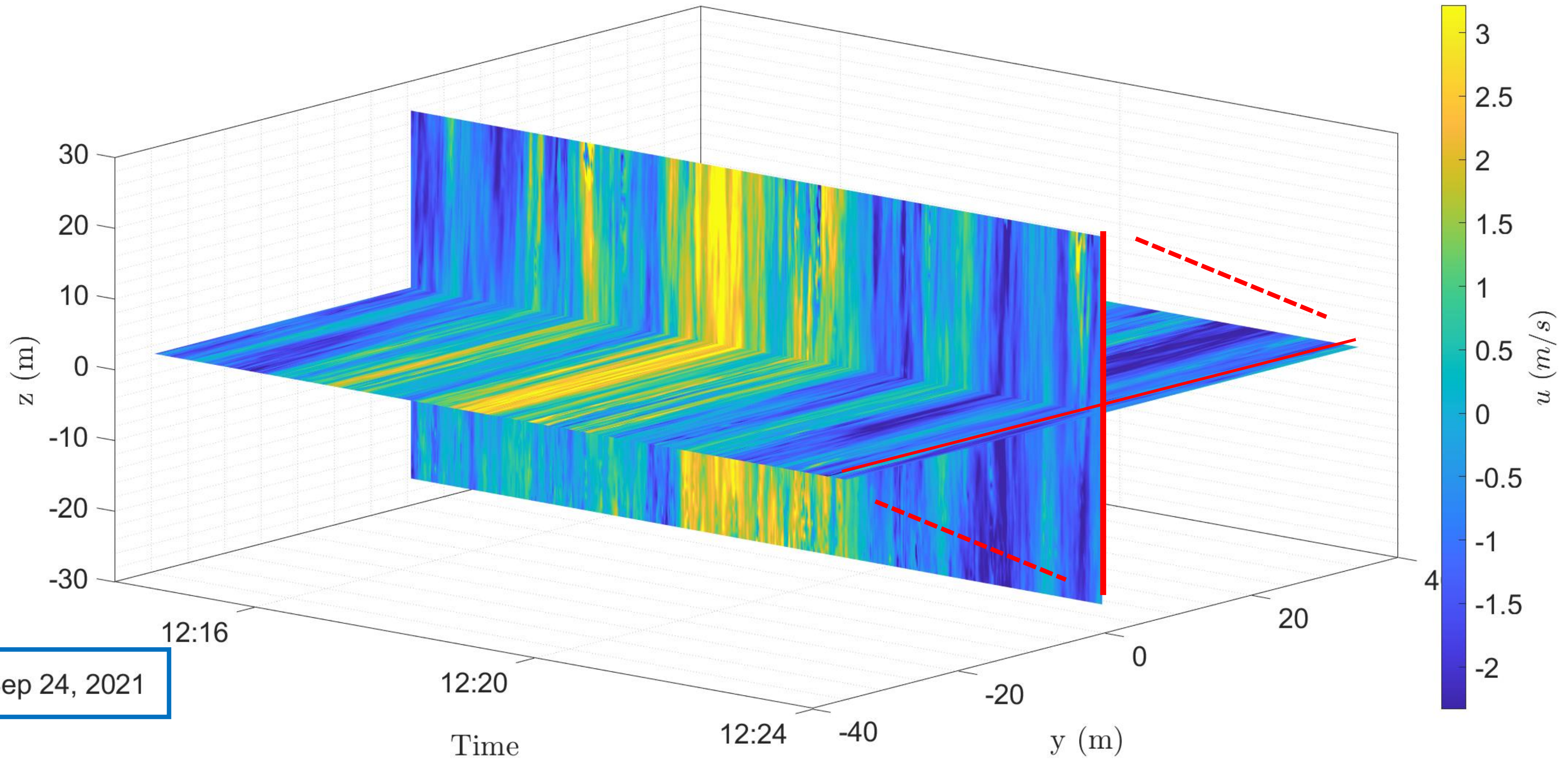


Wind flow mapping

U= 5.91 m/s

I_u= 0.22

I_w= 0.10



Sep 24, 2021

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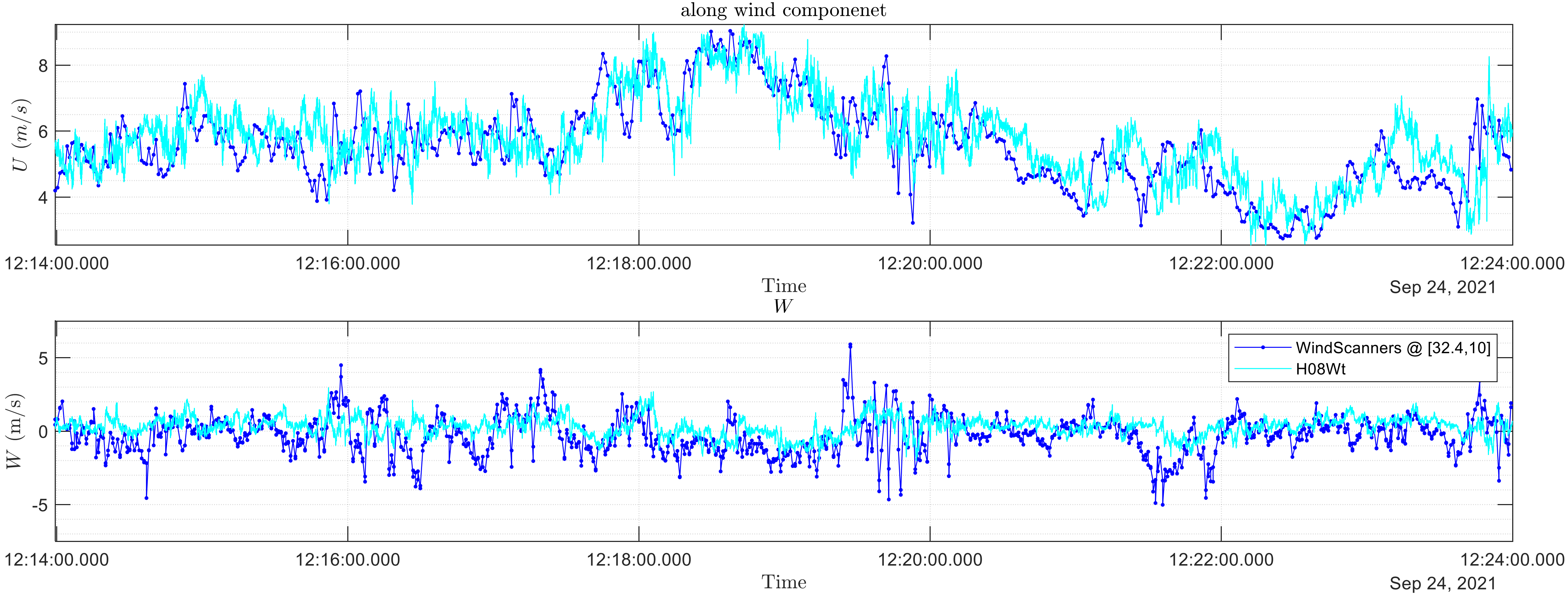
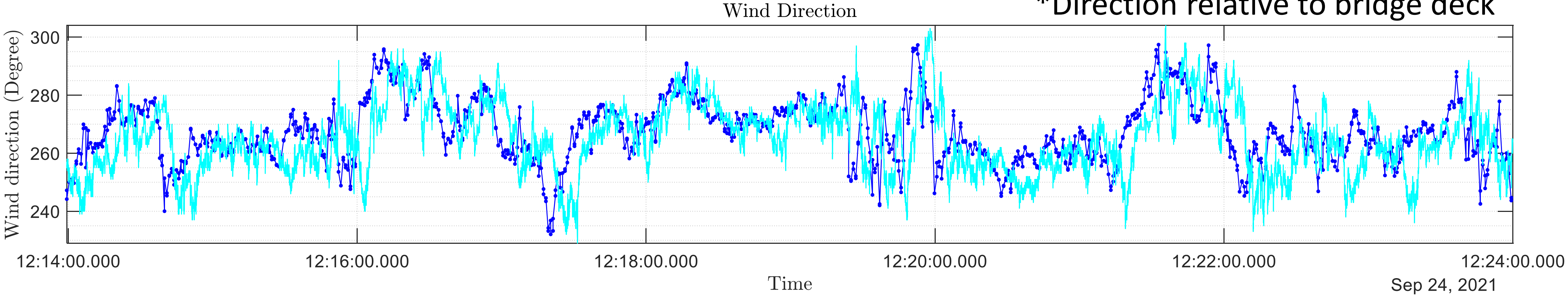
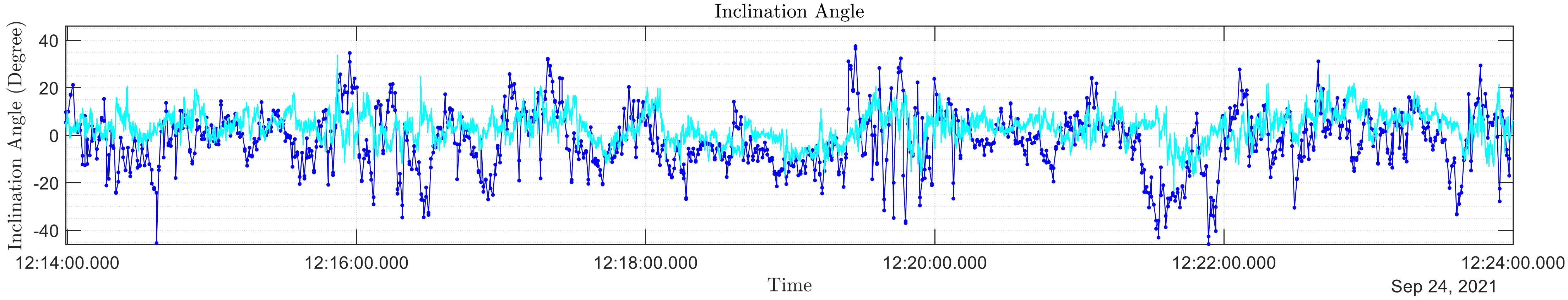
Along-wind and vertical velocities



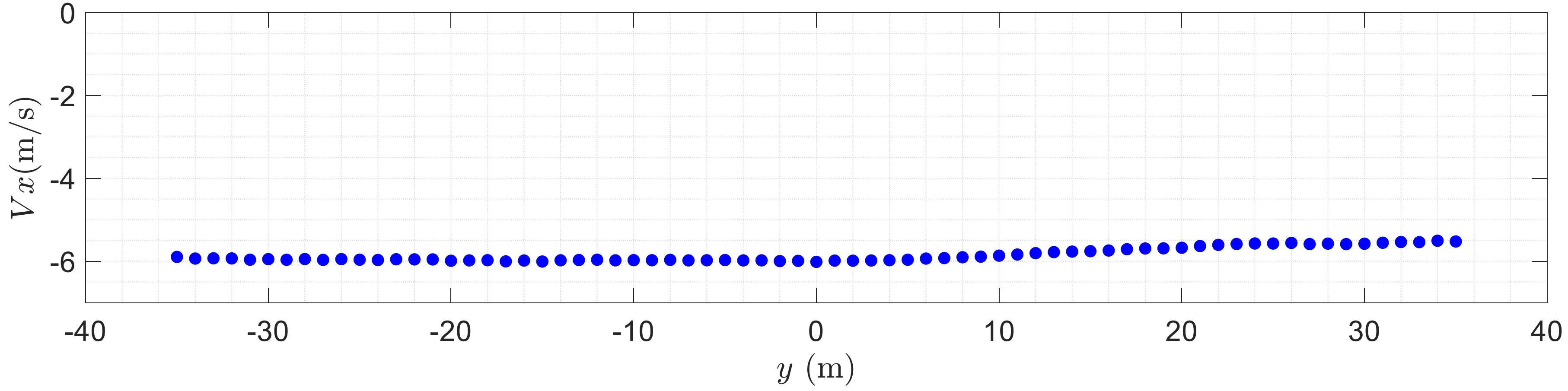
Wind direction and inclination angle

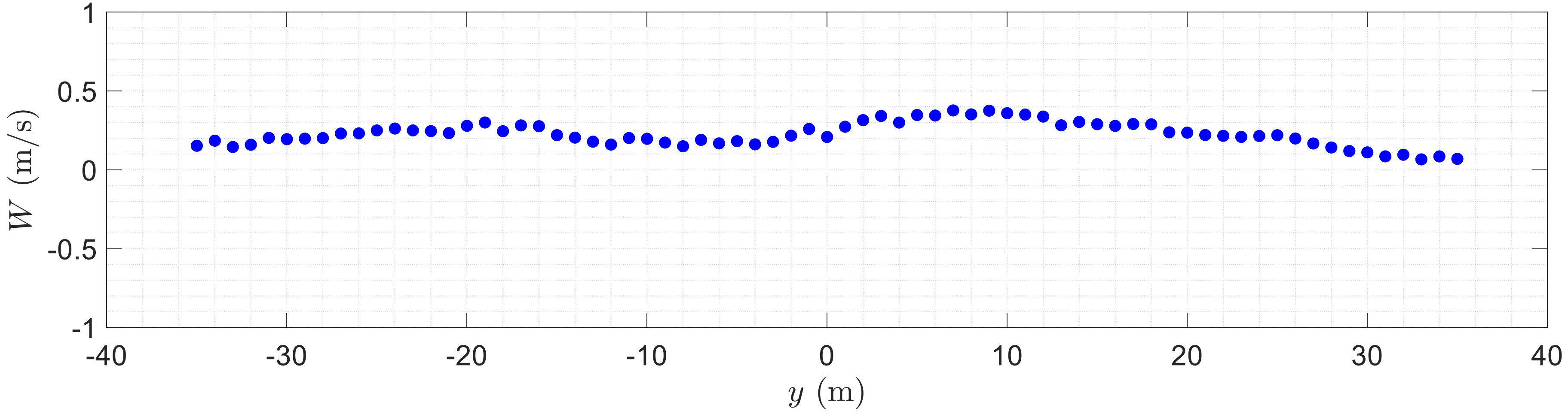
*Direction relative to bridge deck





Mean wind speeds along horizontal line





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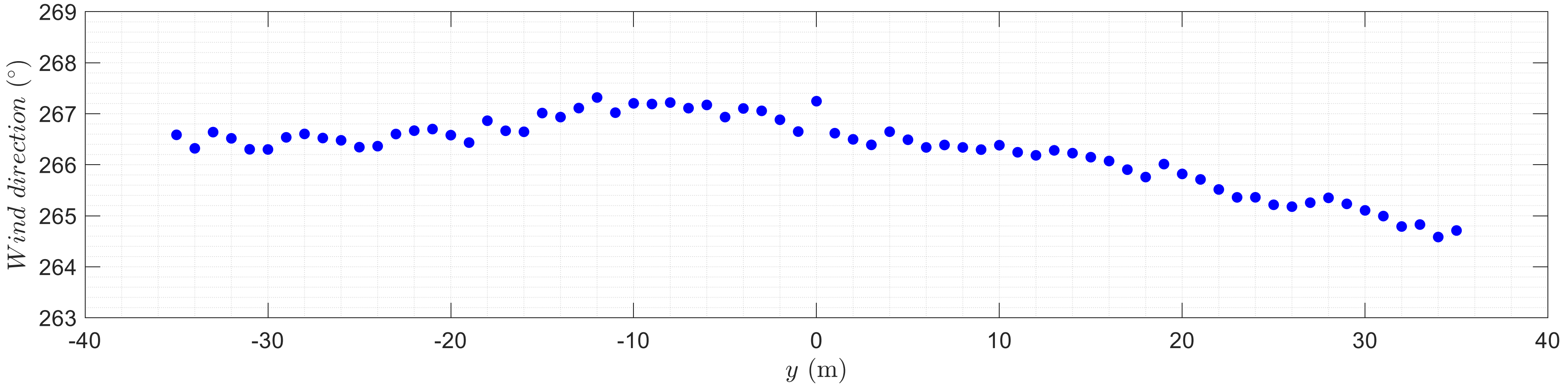
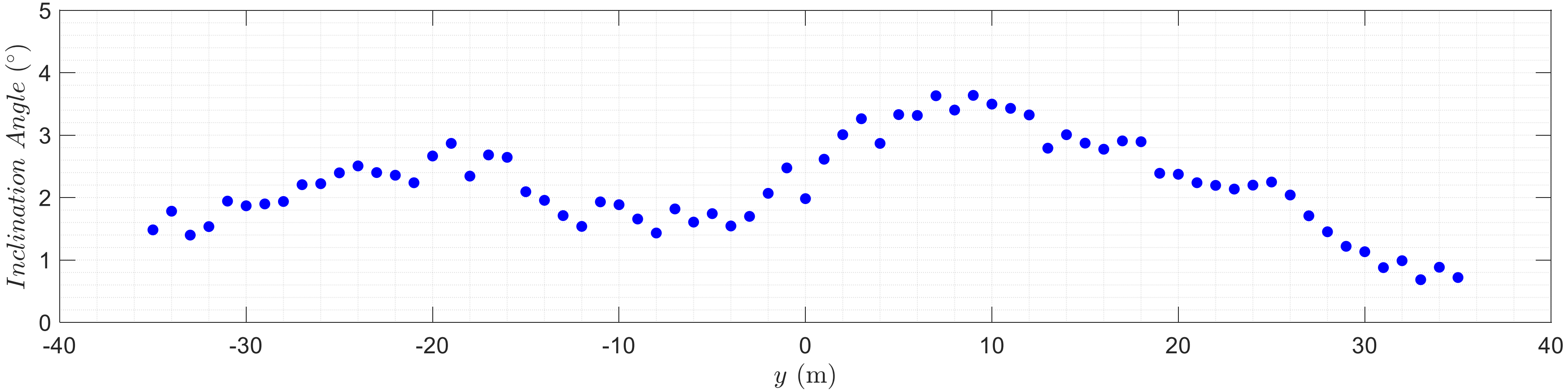
Mean direction and inclination angle along the horizontal line





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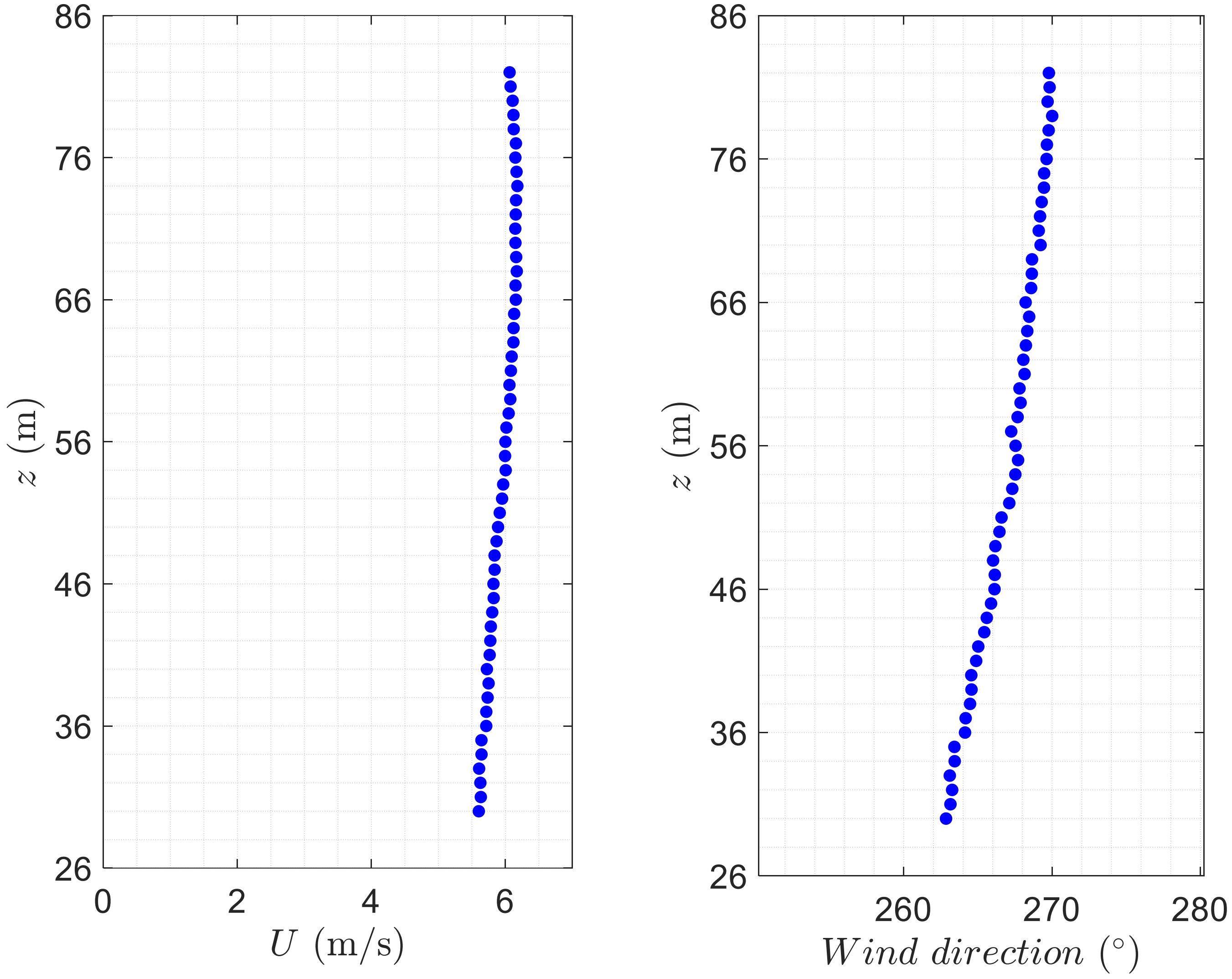
Mean wind speed and direction along vertical line



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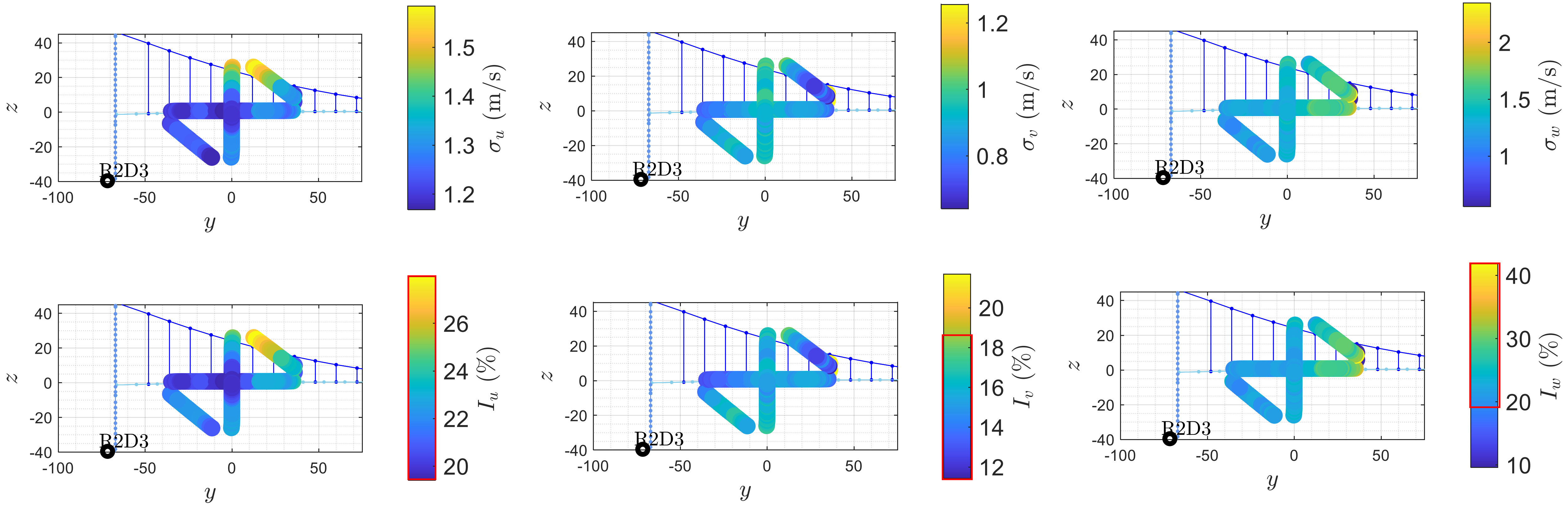
Turbulence Intensities



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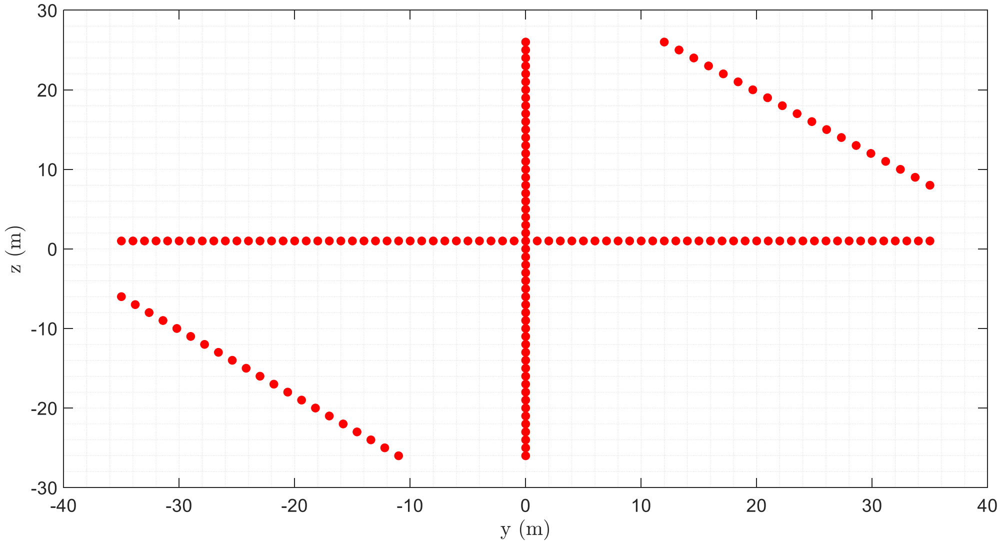
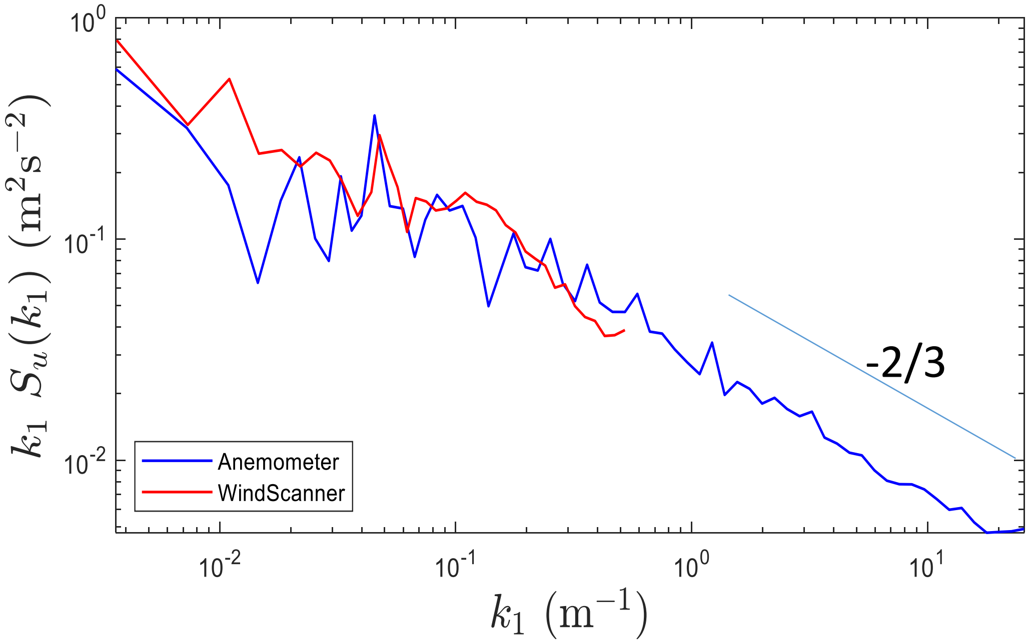
Turbulence spectra





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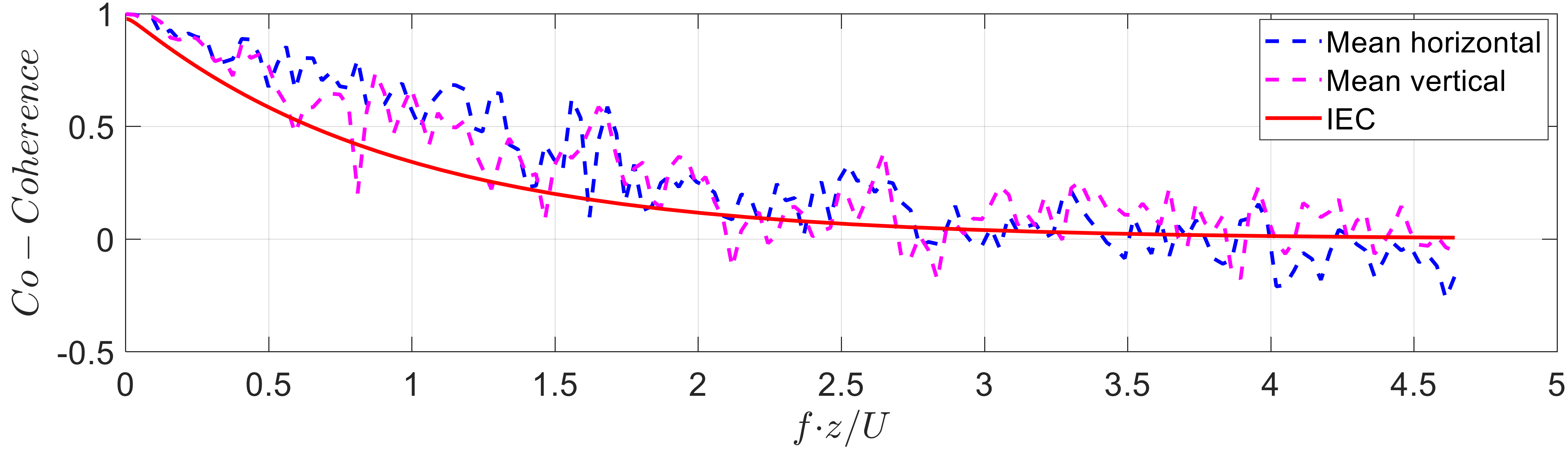
Results

- Coherences (5-meter separation)



IEC 61400-1 Edition 3.0 2005-08
Wind turbines
Part 1: Design requirements

$$\mathrm{Coh}(r,f) = \exp\left[-12\left(\left(f \cdot r / V_{\mathrm{hub}}\right)^2 + \left(0{,}12\, r / L_{\mathrm{c}}\right)^2\right)^{0{,}5}\right]$$

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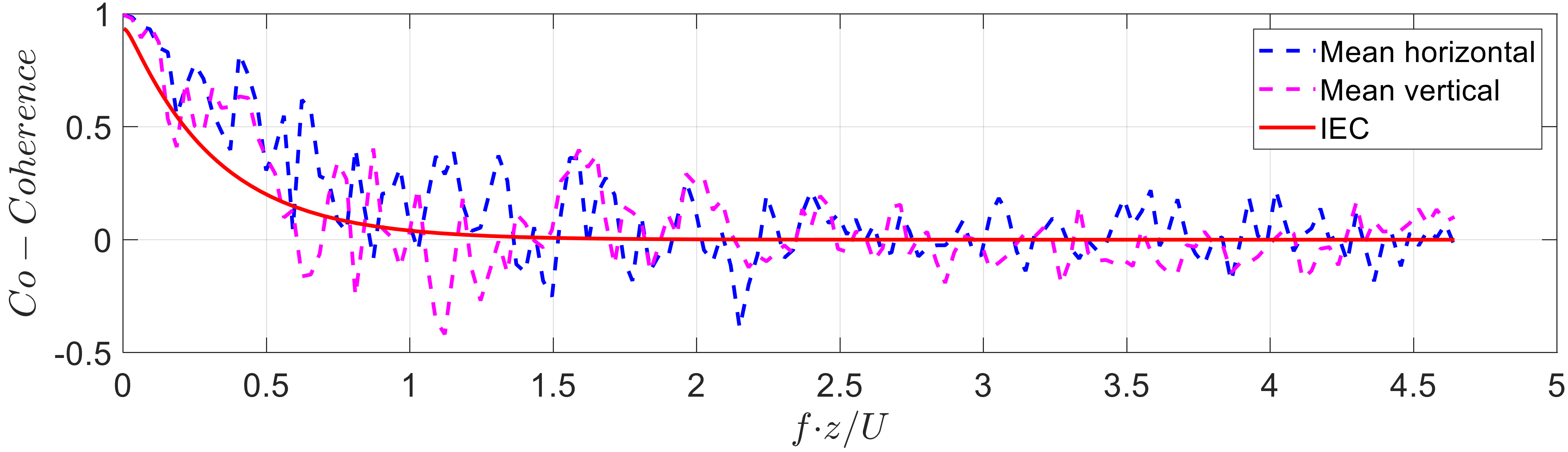
Results

- Coherences (15-meter separation)



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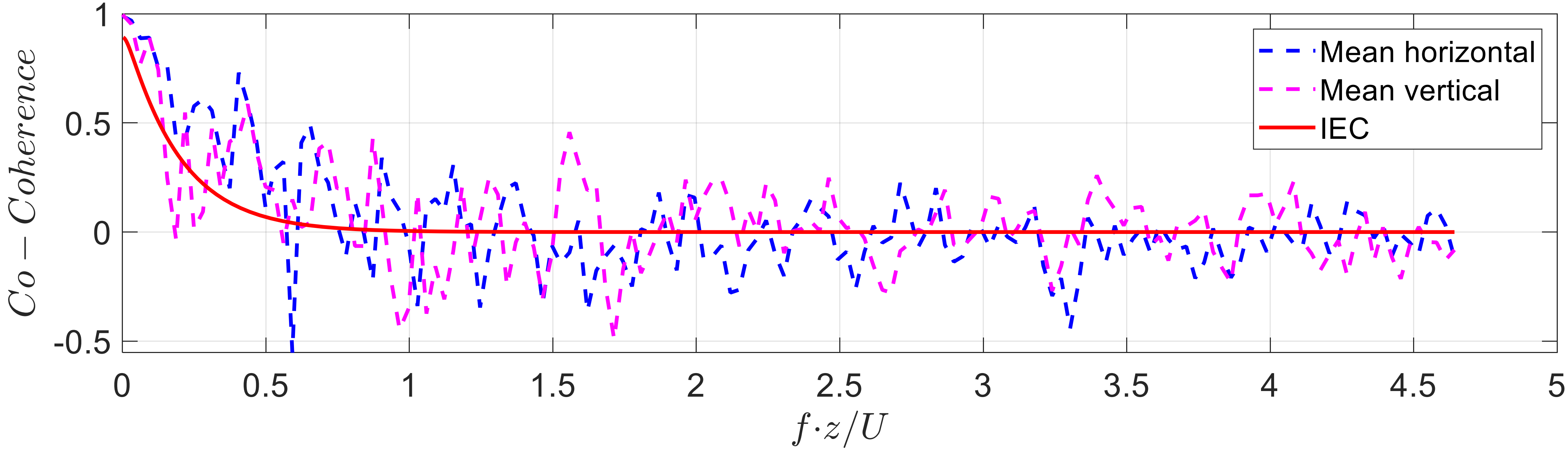
Lateral coherences of u(t)

- Coherence (25-meter separation)



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Concluding remarks and future works

- Novel triple lidar measurement setup for turbulence mapping across a virtual wind turbine rotor developed and implemented.
- Lidar measurements capture well flow field in a broad spatial domain, relevant for wind turbine design.
- Overall good agreement of velocity time series in the simultaneous sonic and lidar measurements.
- Both potential and challenges in the application of lidars.
- Further data analysis in progress.

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- University of Stavanger and DTU lab staff

- UiS wind engineering page: https://windengineeringuis.github.io/index.html
- LIKE page: https://www.msca-like.eu/ and LinkedIn: https://www.linkedin.com/company/msca-like

Thanks for your attention