Assessment of wind conditions at a fjord inlet by complementary use of sonic anemometers and lidars

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http://nn.wikipedia.org/wiki/Uburen#mediaviewer/File:Lysefjordbroen_sett_fra_Sokkanuten.jpg

Background and motivation

- Accelerated development of wind velocity measurement devices based on the remote optical sensing over the past decade.
- Versatile use of lidars in wind energy (wind characteristics in complex terrain, wake studies, wind forecasting, power curve assessment, feed-forward control strategies etc.)
- Wind characterization in related engineering fields.

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- Demonstrate relevance of lidars for assessment of wind conditions for other wind-sensitive structures such as long-span bridges.
- Explore new lidar-based measurement setups and the data interpretation.

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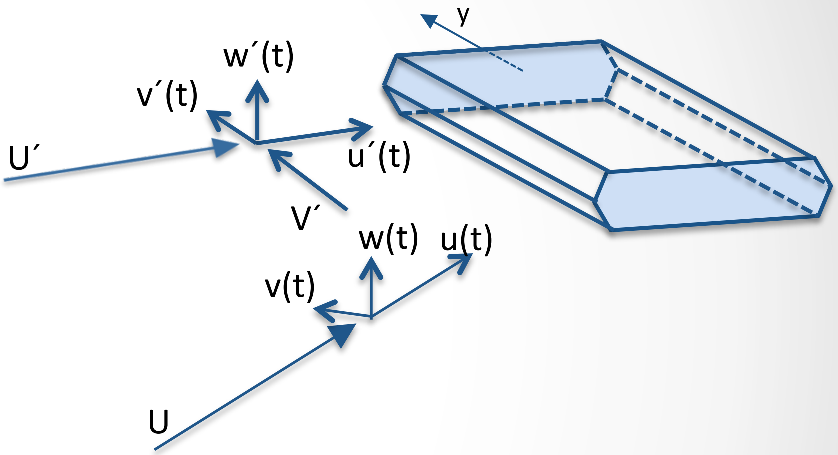
Wind design basis for long-span bridges

- Design mean wind speed (10 min, p=0.02)
- Turbulence intensity, I_u, I_w
- Turbulence spectra $S_u(f)$, $S_w(f)$
- Spatial structure of turbulence:

  Cross-spectra $S_{uu}(\Delta y,f)$, $S_{ww}(\Delta y,f)$, Co-coherence
- Other aspects:

  Flow uniformity in complex terrain

  Non-stationarity…



- Prior to bridge construction, deployment of sonic anemometers limited to locations away from the future structure itself.
- Lidars can be used to establish the relationship between the conditions observed by the sonic anemometers and those in the (middle of the) fjord.
- Flow structure along the bridge span, wind-structure interaction etc. can also be studied.

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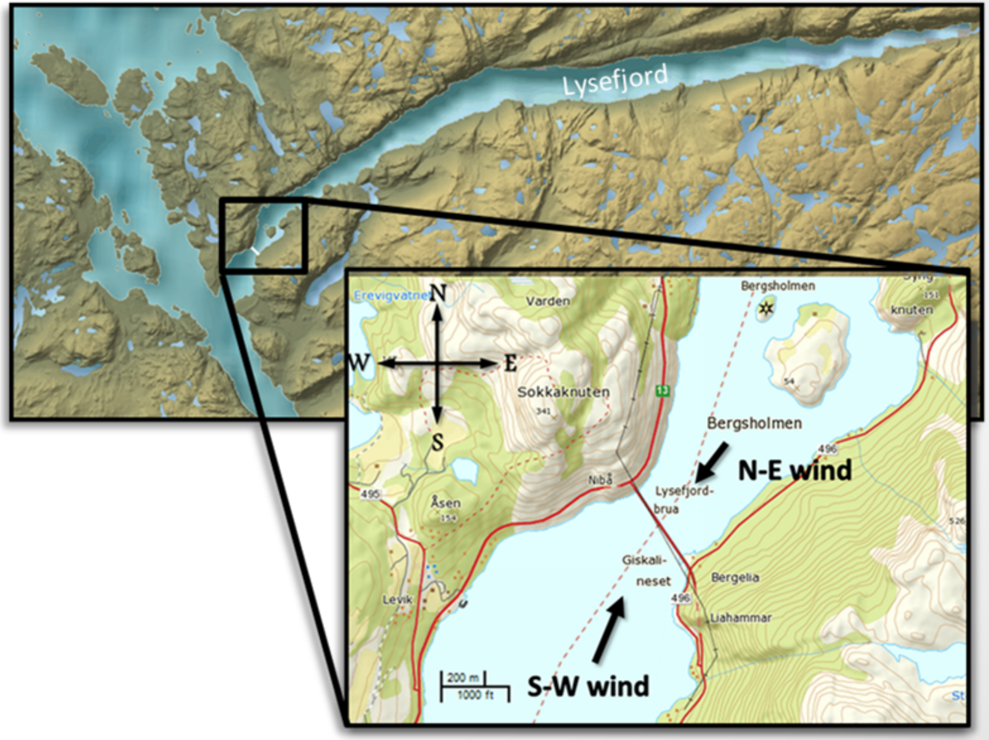
Pilot project on wind characterisation by lidars at Lysefjord bridge

Main bridge characteristics:

- 640 meter span
- Main span 446 m
- Towers 105 m tall
- 12 main cables
- Opened in 1997



- Design wind speed:

  Mean value: 36 m/s

  3-seconds gust 49 m/s

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Overview over monitoring activities

1. Long-term wind and response measurements

Part 1A (Nov 2013 -): 5 sonic anemometers and 4 accelerometers.

Part 1B (Mai 2014 -): 3 additional anemometers and 6 accelerometers.

Supported by the Norwegian Public Road Administration,
the University of Stavanger and
NORCOWE (Norwegian Center for Offshore Wind Energy).
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2. Wind characterization by lidars

Part 2A (March – June 2014): one long-range pulsed Doppler lidar
Part 2B (1 week in May 2014): two synchronized short-range WindScanners
Supported by the Norwegian Public Road Administration,
NORCOWE (University of Bergen /CMR), Leosphere A/S, UiS and the Danish Technical University.

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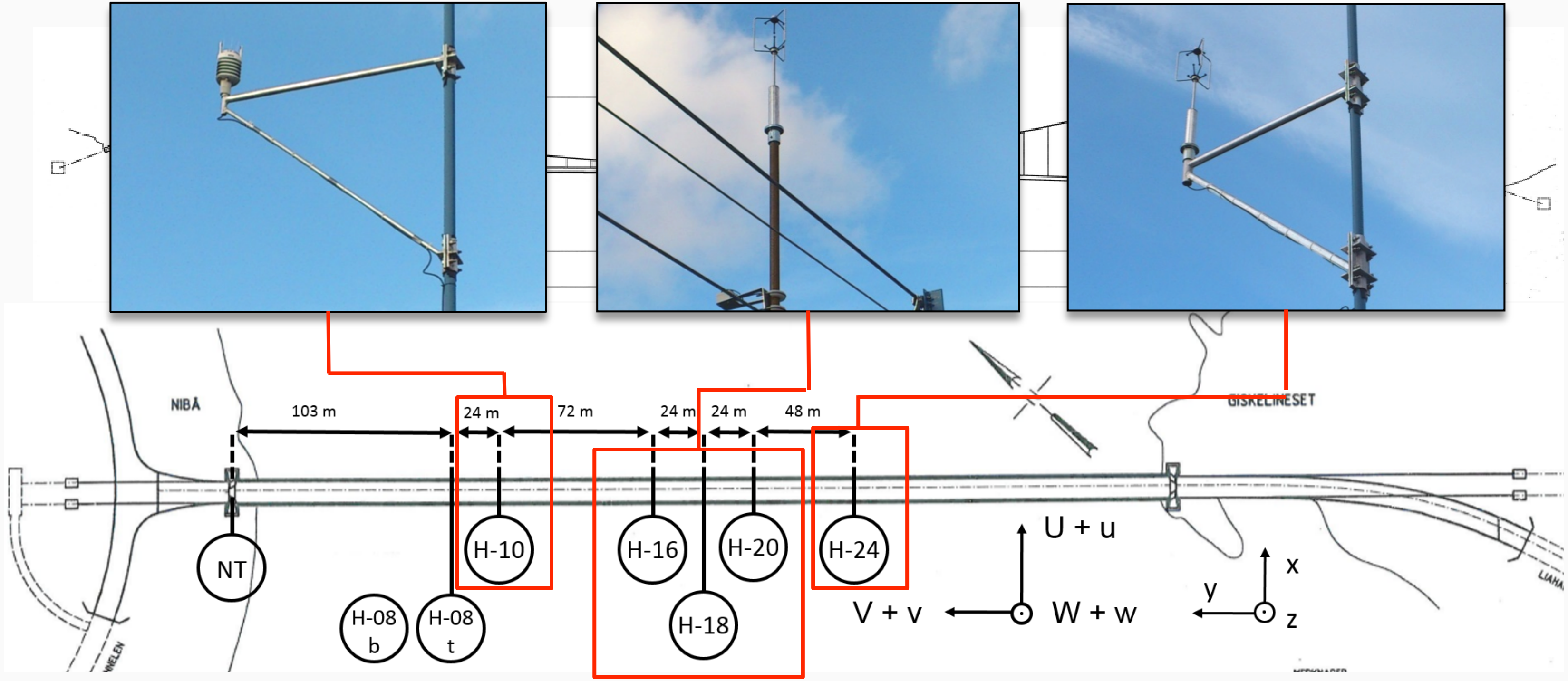
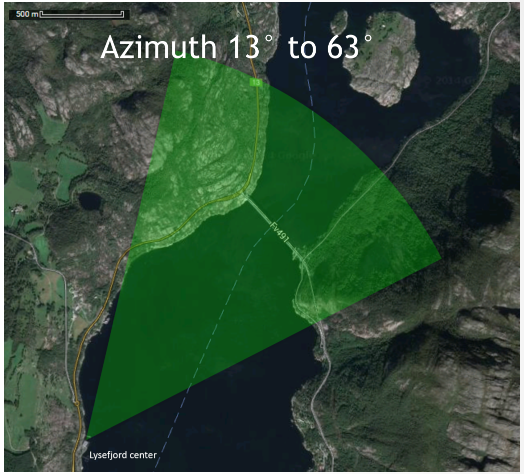
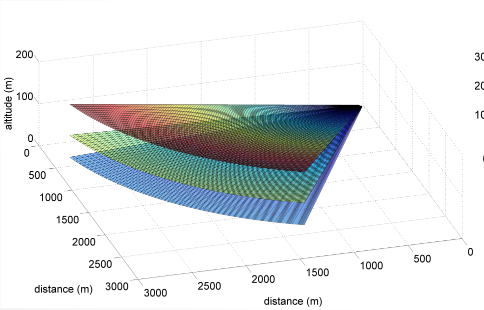
Long term set-up: Sonic anemometers Wind MatsterPro 1561-PK-020 and one Vaisala Weather Station WXT520 (H-10)



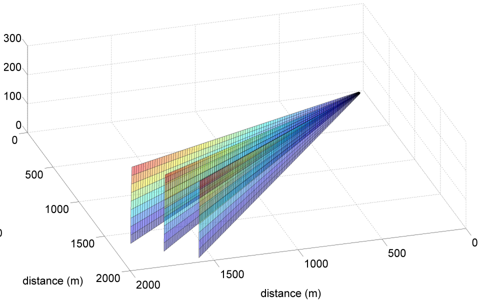
Wind flow characterization by a long-range pulsed Doppler lidar (March 2014 - June 2014)

- Collaboration between UiS and NORCOWE (UiB, CMR and Leosphere)
- Scanning modes:
  - Doppler Beam Swinging mode (DBS)
  - Plan Position Indicator mode (PPI)
  - Range Height Indicator mode (RHI)
  - Sequential Fixed Line of Sight mode (LOS)





PPI, elev. 0.8°, 1.8° and 3.2°



RHI Azimuth 37 °,38 ° and 39 °

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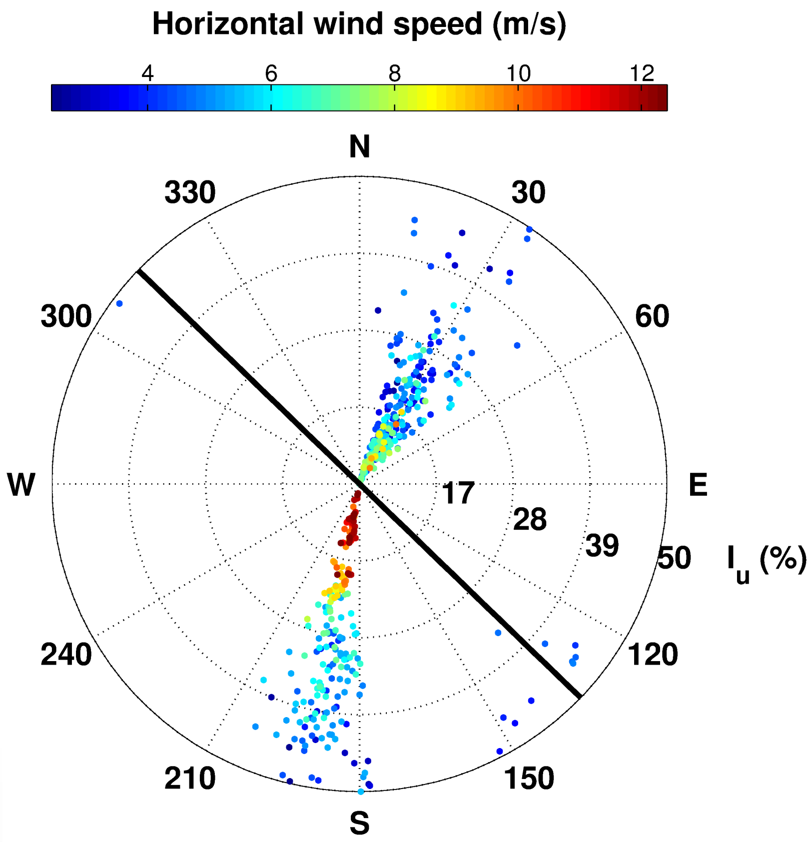
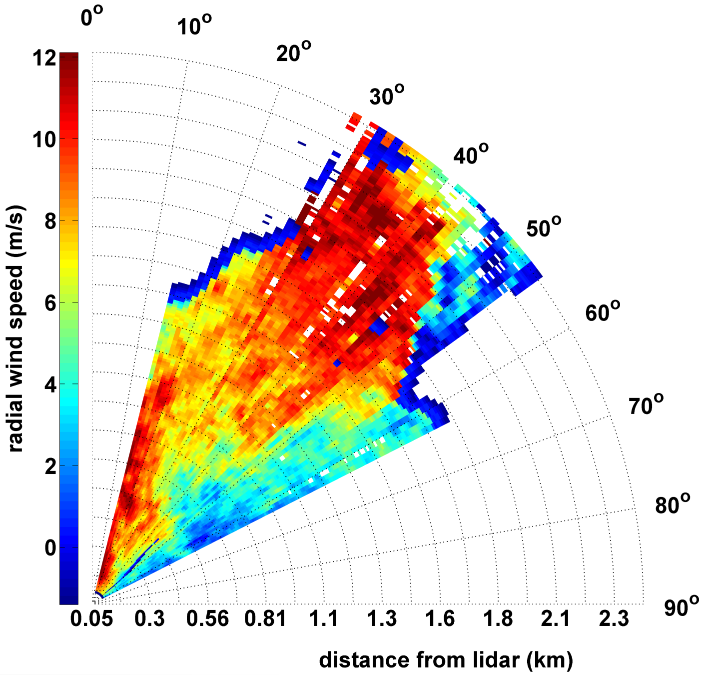
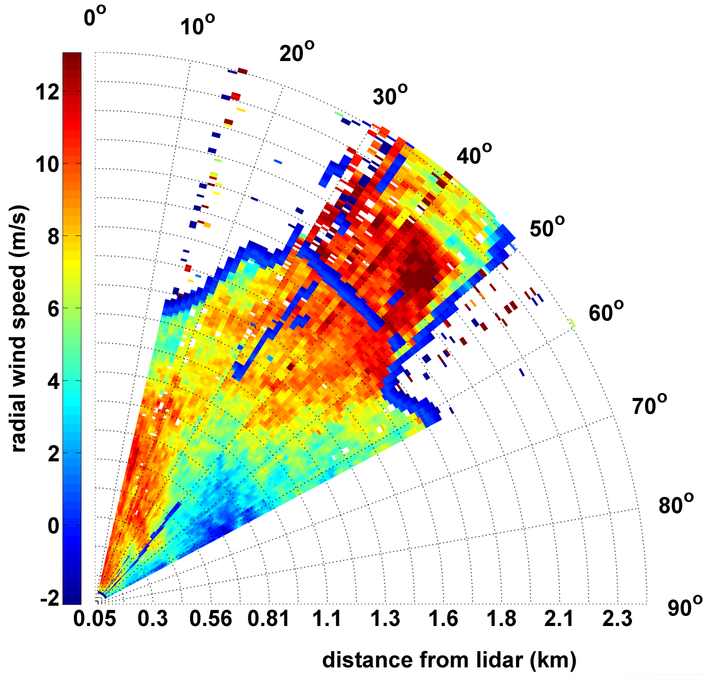
Example: Mean wind speed and turbulence intensity I_u recorded by sonics on 22.5.2014



Example of a Plan Position Indicator mode (PPI) data

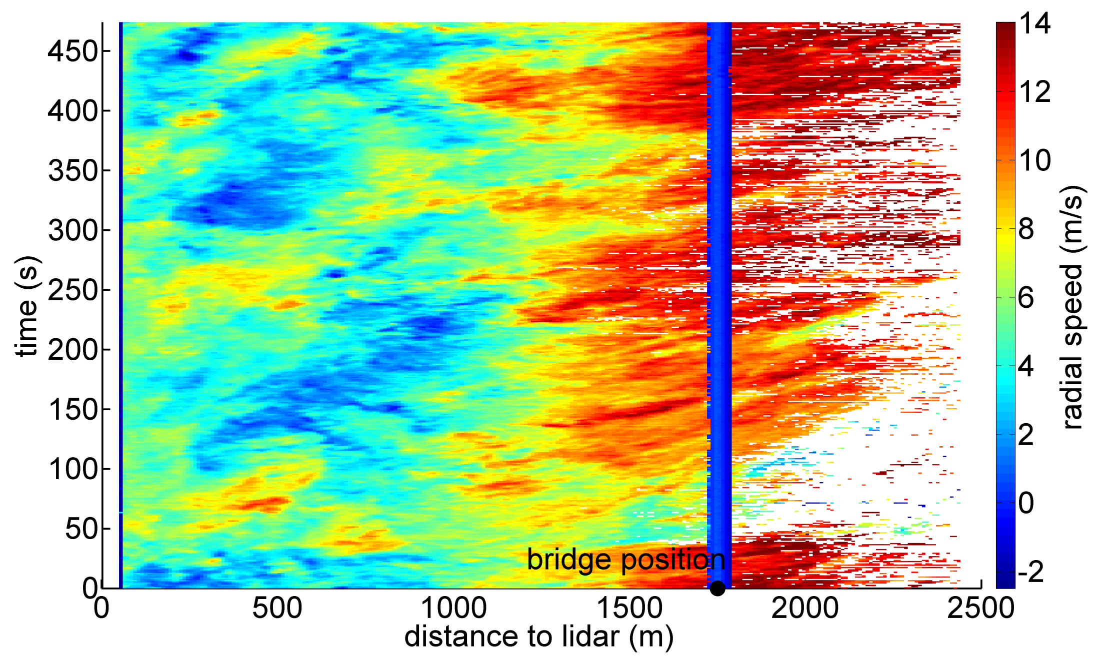


22.5.2014, 18:19:23 elev=3.2°



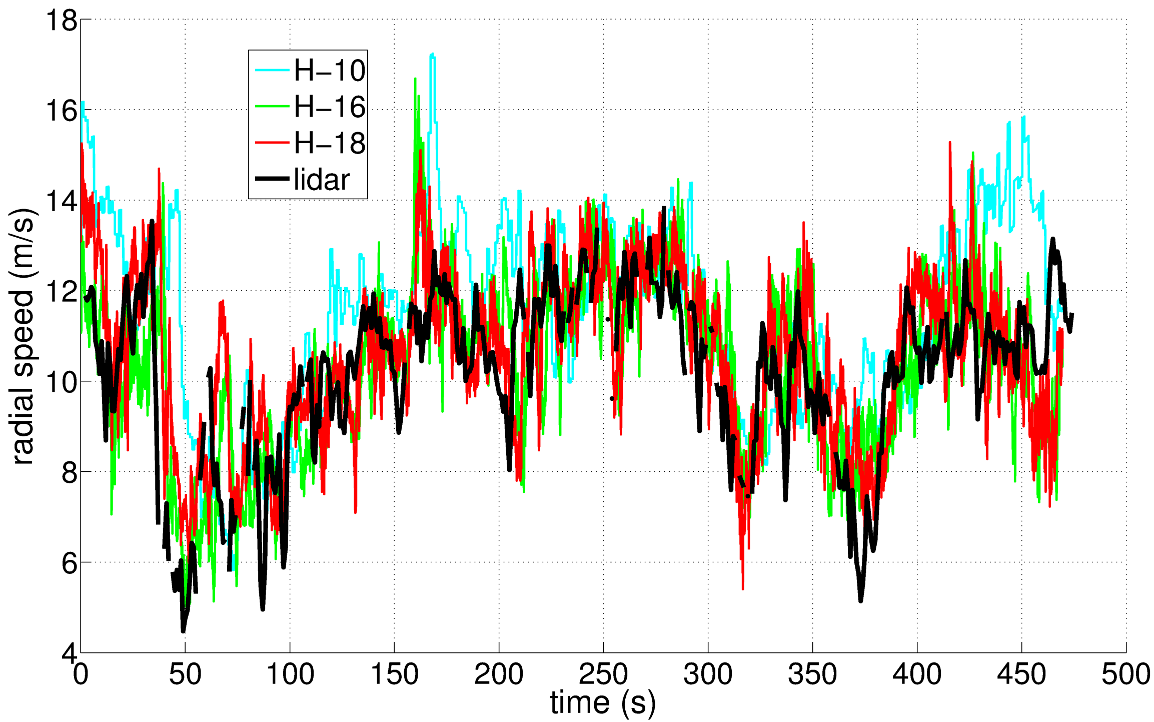
22.5.2014, 18:19:10 elev= 1.8°

Example of a Sequential Fixed Line of Sight mode (LOS) measurement, elev=1.8° azim=39°



Radial wind velocity recorded by a LOS scan on 22.05.2014 starting at 17:12:06

Radial wind velocity recorded by a LOS scan and by the sonic anemometers 30 m further downstream



SENSORS	Mean Radial speed (m/s)	RMS radial speed (m/s)
Lidar	10.4	1.8
H-10	11.5	2.1
H-16	10.5	1.8
H-18	10.6	1.8

22.05.2014, starting at 17:12:06

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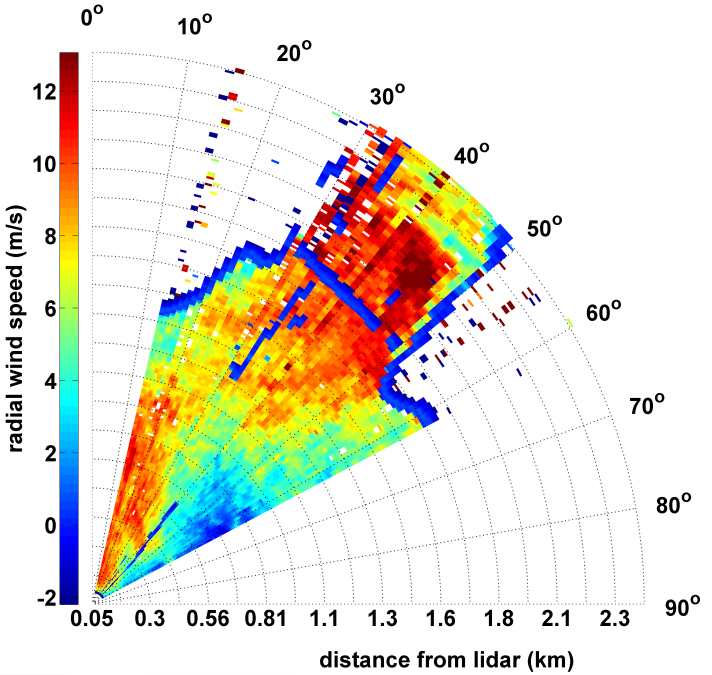
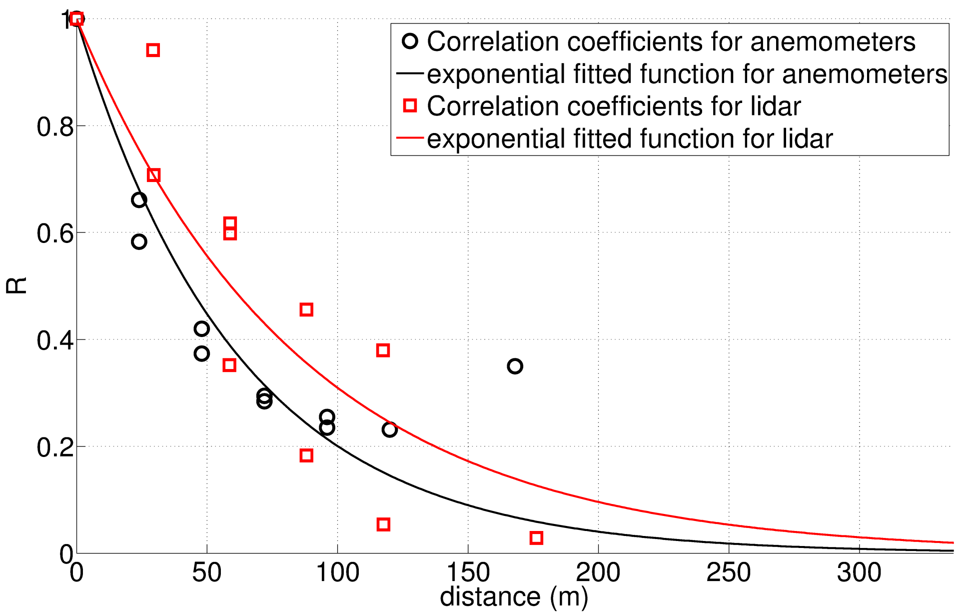
Example of a Plan Position Indicator mode (PPI)





22.5.2014, 18:19:10 for elevation =1.8°

Cross-correlation coefficient for u´(t) for separations along the bridge, 18:15 to 18:25, 22.05.2014

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Multi-lidar measurements, May 2014
Short range WindScanners deployment

- Two short-range WindScanners developed by the Technical University of Denmark, building on ZephIR, deployed on the bridge walkway on the West side.
- Synchronized to map the airflow in different planes (horizontal and “vertical”) SW from the bridge, and operated remotely.
- High-frequency, separate LOS data also recorded.
- The Doppler spectra averaged such that LOS wind velocities were provided at about 390 Hz and the scan pattern frequency was 1 Hz.
- Scanning sequences devoted to capturing the spatial characteristics of the inflow, as well as various forms of the bridge signature in the airflow.

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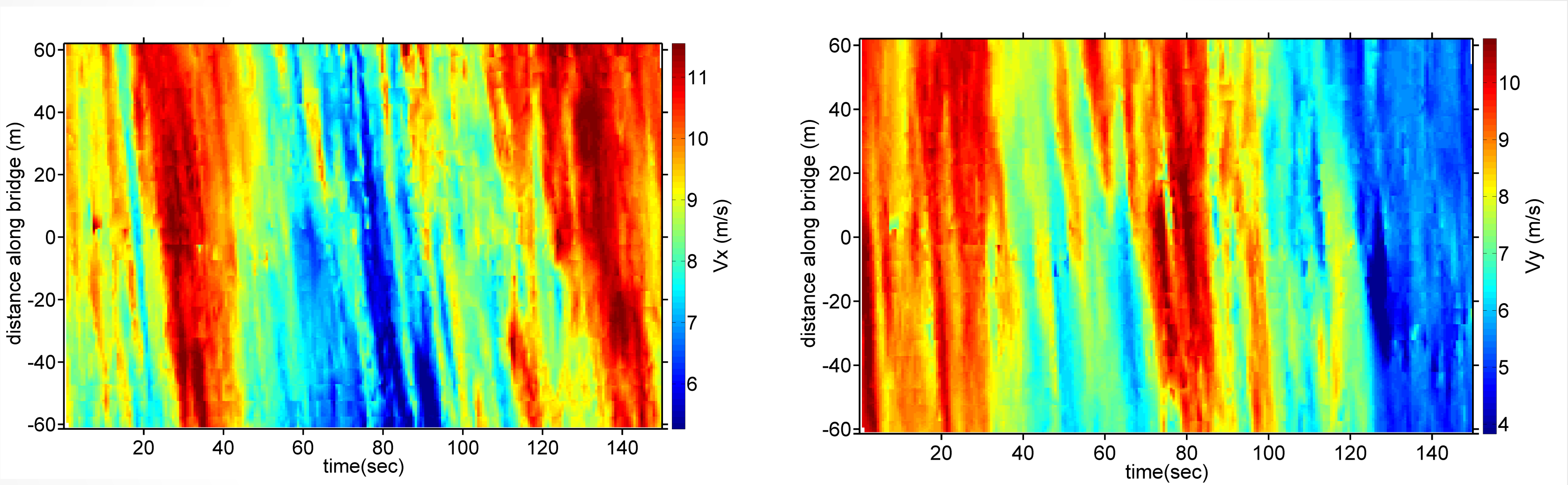
Horisontal wind velocity ”scan” 40 m in front (SW) of the bridge



22.5.2014, 17:20, Horizontal wind component perpendicular to (left) and along (right) the bridge

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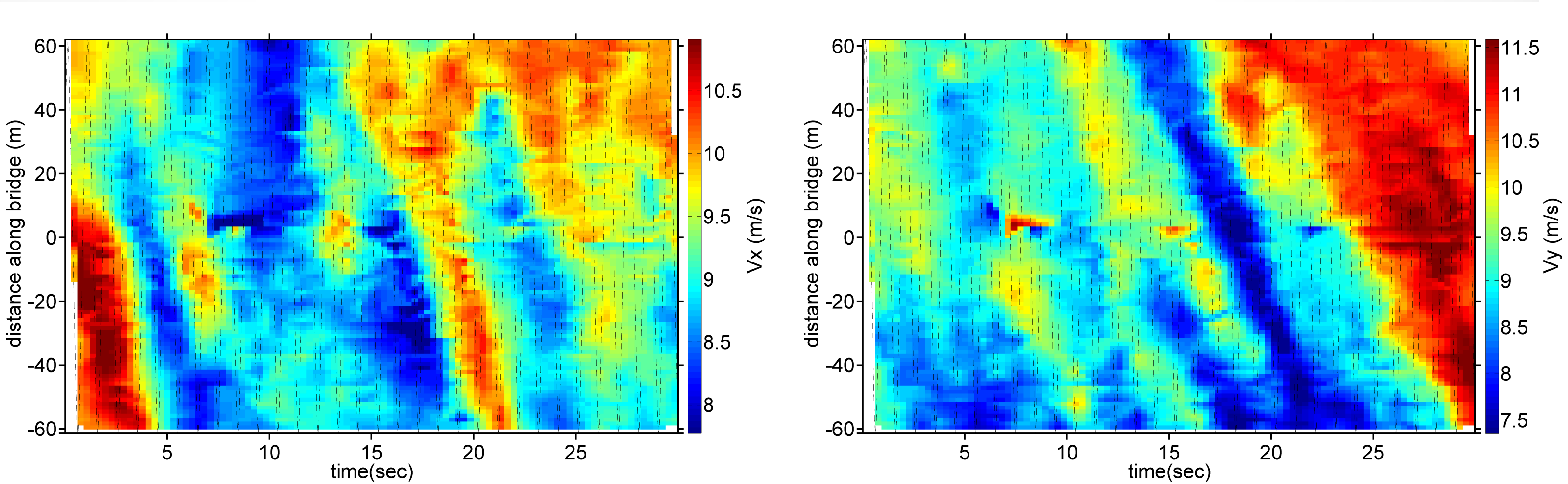
Horisontal wind velocity "scan" 40 m SW of the bridge



22.05.2014, 17:20, Horizontal wind component perpendicular to (left) and along (right) the bridge. Scan pattern overlaid the measurements.
=>Wind from South

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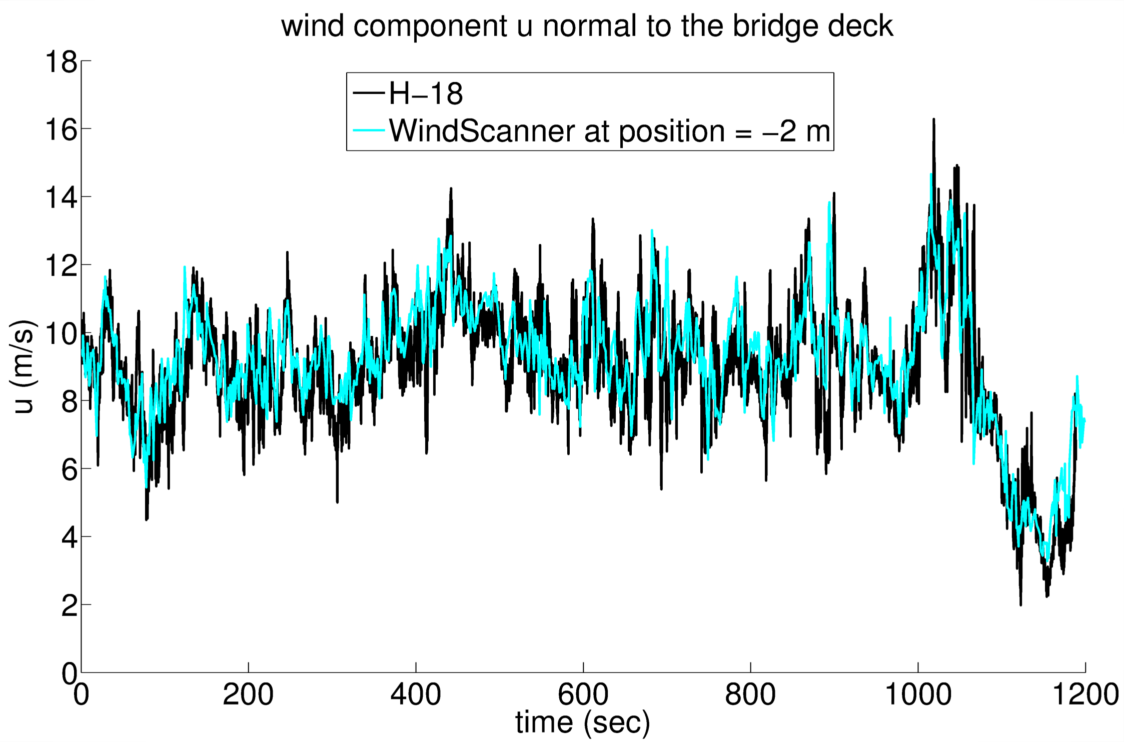
Wind velocity normal to the bridge as observed by the WindScanners and the sonic anemometer



starting at17:20, 22.5.2014

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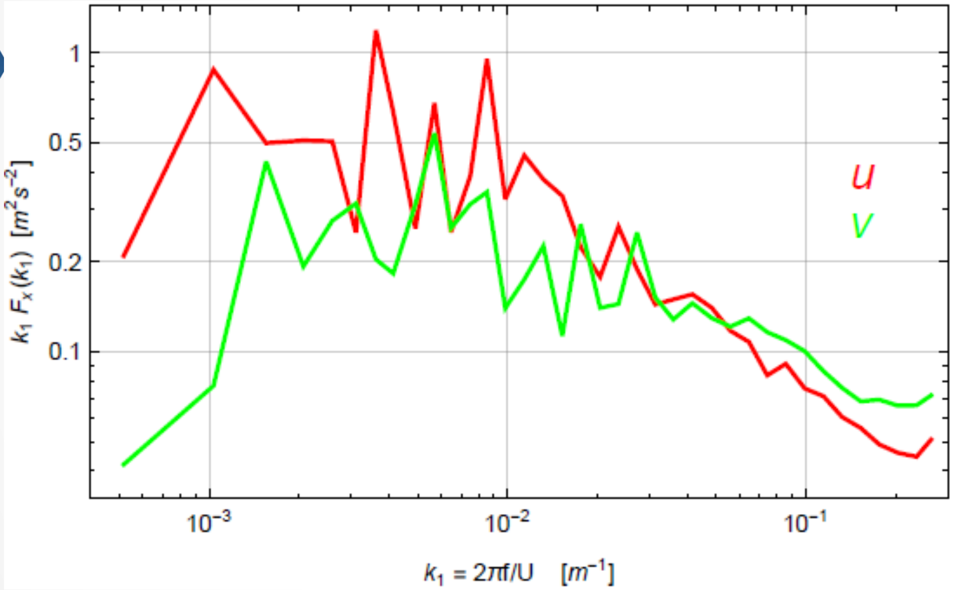
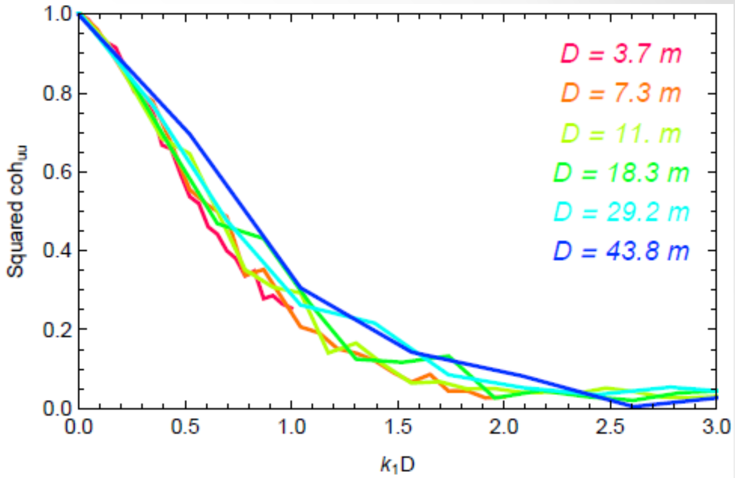
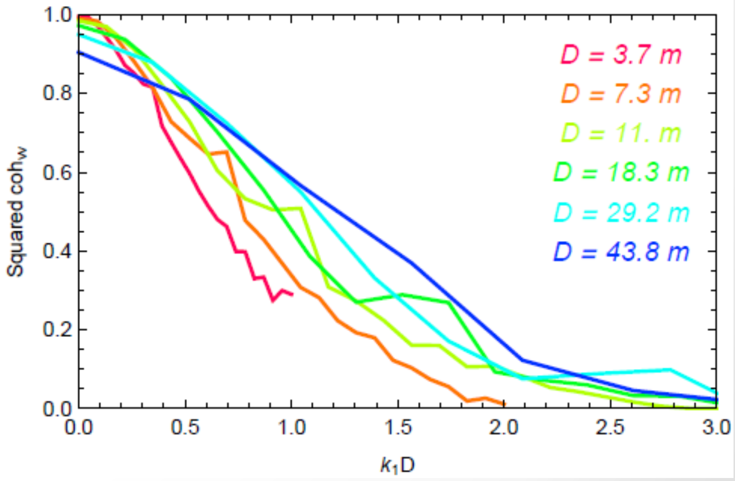
Spectra and coherence estimates from WindScanners data



22.5.2014, 17:20, ensamble average of
~15 min long time-series, ~30 minutes data





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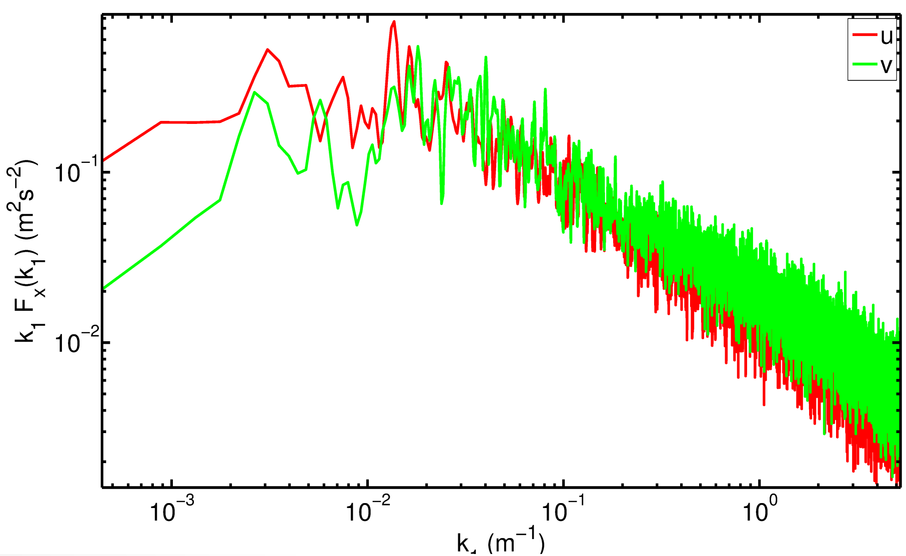
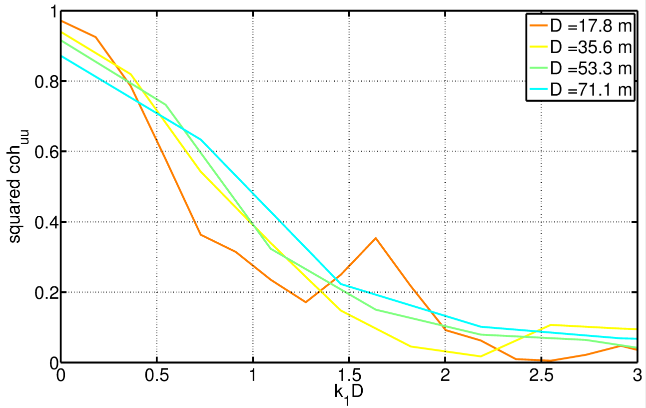
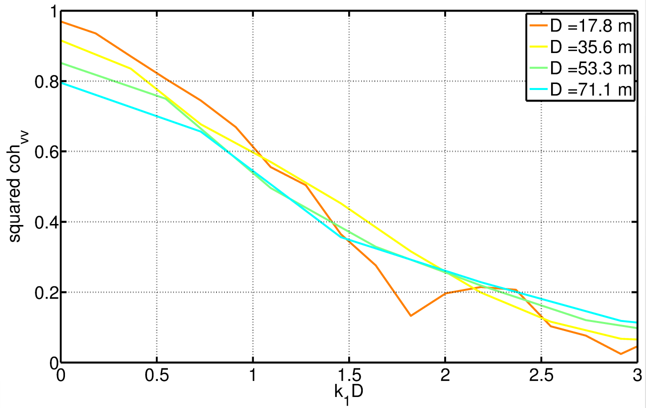
Spectra and coherence estimates from sonic anemometer data







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22.5.2014, 17:20
average for five anemometers
20 minutes long records

Summary

- Wind measurement techniques based on optical remote sensing offer valuable supplement to wind monitoring by cup and sonic anemometers for long-span structures, in particular for surveying large, low-frequency wind gusts.
- Wind-structure interaction may also be studied.
- Synchronized multi-lidar arrangement fundamental to capture the spatial character of turbulence.
- Second order statistics based on lidar data relates well to the results based on «point» measurements.
- Further work needed to adress the effect of volume averaging by lidars on turbulence characterization in more detail.

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