The COTUR project: Remote sensing of offshore turbulence for wind energy application

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In collaboration with the University of Bergen, the University of Stavanger and Equinor Energy AS, the Norwegian Research Centre (NORCE) is currently performing a one-year measurement campaign at Obrestad Lighthouse in southwestern Norway. The field campaign aims to improve our current understanding of the offshore wind coherence and its impact on the wind-induced response of large floating offshore wind turbines.

This is the first time that such extensive near-shore field measurements are performed in Norway. The collected data is also unique internationally and the subsequent data analysis is highly relevant for load estimations on multi-megawatt offshore wind turbines. For example, the collected data can help to reduce uncertainties in dynamic wind load modelling, especially concerning large offshore wind turbines with rotor diameters in the 200 m range.

Obrestad Lighthouse is located on a plateau, approximately 25 m above the sea level, and is thus an excellent basis for the COTUR measurement campaign.

Research questions to address

The data collected from this measurement campaign is used to address the following relevant key research questions:

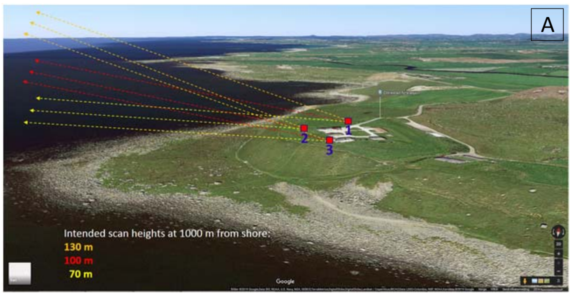
- What are the characteristics of the horizontal coherence offshore?
- How does horizontal coherence relate to different atmospheric conditions (in particular stability) offshore?
- How does the observed horizontal coherence compare to the industry standard?

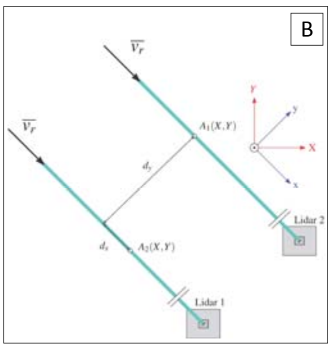
Measurement set-up and strategy

The primary instruments deployed at Obrestad Lighthouse are three WindCube 100s scanning LiDAR systems, which are placed in a triangular set-up. The scanning LiDAR systems perform synchronized measurements and record the wind speed at intervals of 25 m along their respective laser beam, up to 3 km from shore and once per second. Each LiDAR's radial wind speed measurements is orientated into the mean wind direction and the three laser beams are kept parallel to each other. This provides different lateral separations between the respective laser beams, depending on the azimuth direction. Moreover, measurements are performed for three distinct altitudes which cover the lower part, the hub-height and the upper part of modern offshore wind turbines. Additionally, both a vertical measuring WindCube V1 and a HATPRO passive microwave radiometer is installed at the site. These two instruments provide data on the vertical wind profile and the vertical temperature and humidity profile, respectively.

The coherence is modeled as:

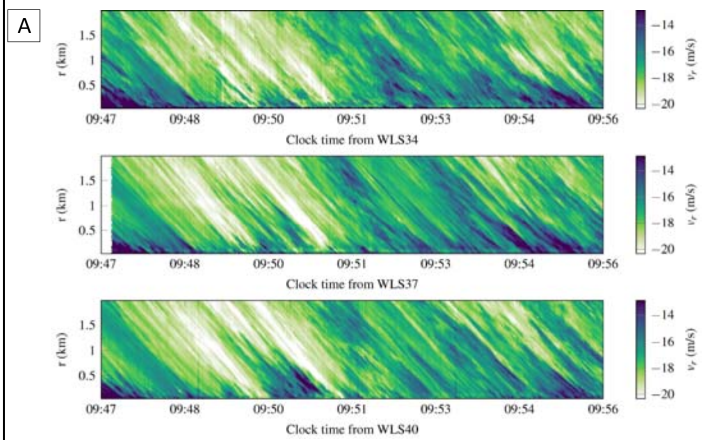
$$\gamma_{uu}(f,d_x,d_y) = \exp\left(-\frac{f}{\bar{u}}\sqrt{[C_x d_x]^2+[C_y d_y]^2}\right)\cos\left(\frac{2\pi d_x f}{\bar{u}}\right) \quad [1]$$

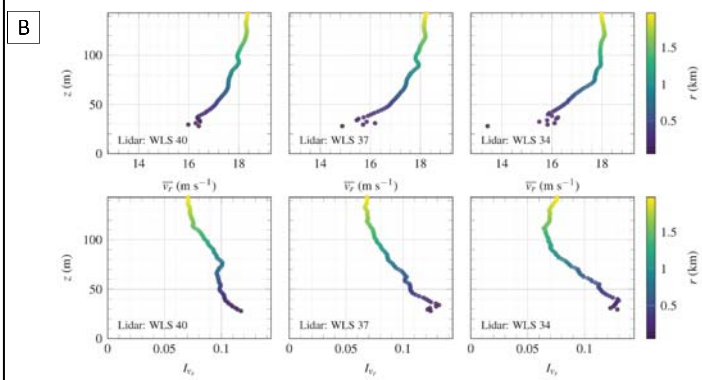




Figures: Sketch of the performed scan pattern, illustrating the vertical [A] and horizontal [B] distances between the LiDAR laser beams, and picture of the installed measurement instrumentation at Obrestad [C].

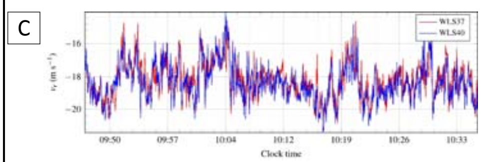
Preliminary results



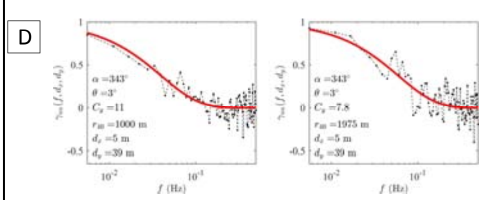


[A] Snapshot of ten minutes of instantaneous along-beam radial wind speed recorded on 30-09-2019 by each of the scanning LiDAR's, with a wind and LiDAR azimuth direction of 343° and an elevation angle of 3.4°. The probe length was 50 m with 50% overlapping, leading to ranges gates of 25 m.

[B] Profiles of mean radial wind speed (upper panels) and turbulence intensity (lower panels) determined for the radial wind velocity records from 09:47 to 10:36 on 30-09-2019. The increasing heights are associated with increasing scanning distances.



[C] Time series of the radial wind speed at a height of ca. 140 m above the sea surface at a scanning distance of 1.9 km recorded from two of the scanning LiDAR systems. The cross-wind distance between the two LiDAR laser beams was 39 m.



[D] Co-coherence estimates in the horizontal plane of the along-beam component for two distinct LiDAR range gates using a single 50-minute wind record from 09:47 AM to 10:36 AM on 30-09-2019. The crosswind and the along-wind separations were 39 m and 5 m, respectively. The red curve corresponds to the least-square fit of equation *[1]*.

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