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Wind coherence measurement by a single pulsed Doppler wind lidar

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Abstract

A single pulsed Doppler wind lidar, deployed at the FINO1 platform in the North Sea, has been used to monitor the lateral and vertical coherence of the along-wind component. To maximize the sampling frequency of the monitoring system, a particular configuration based on small sweeping angles around the mean wind direction is used. The set-up provides wind velocity measurement with an increasing cross-flow separation with increasing distances from the lidar. We present hereby preliminary results from the analysis of the Plan Position Indicator scans carried out with a sampling frequency of 0.13 Hz, and the Range Height Indicator scans sampled at 0.19 Hz. The mean velocity and the turbulence intensity indicated a sufficiently uniform flow, which was verified by the calculation of the along and crosswind turbulence length scales. The lateral and vertical coherence was estimated based on multiple 10-minutes samples, for a mean wind velocity ranging from 10 to 14 $\mathrm{m\,s^{-1}}$. For the conditions examined, the measured coherence showed a good agreement with the IEC model for low and medium cross-flow separations, and a fairly good agreement with the Frøya model for large separations.

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Pulsed wind lidar, FINO1, Offshore wind, Coherence, Wind turbulence, Wind load, Wind turbine

1. Introduction

The co-coherence is used to quantify the in-phase correlation of the wind velocity fluctuations and is therefore a governing parameter to estimate wind loads on structures. A more accurate description of the lateral and vertical co-coherence for the along-wind component may become necessary for offshore wind turbines considering the increasing diameters of blades. Unfortunately, full scale measurements of the co-coherence remains sparse in the literature. The lateral co-coherence has been traditionally measured for applications on long-span bridges [1–3], while vertical coherence has been mainly studied on flat terrain for towers, high-rise buildings and chimneys [4,5]. To study dynamic wind loads on wind turbines, both the lateral and the vertical coherence is required. To the authors knowledge, only

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in [6,7] both lateral and vertical coherence in conditions representative for offshore areas have been addressed. The limited lateral separations accessible by mast measurements may be overcome by the use of Doppler wind lidars, but their applications for coherence measurement remains unexplored so far. A system of multiple-wind lidars is desirable to study wind coherence, by allowing the use of a higher sampling frequency than with a single lidar and the retrieval of the different wind components [8–11].

However, if only a single wind lidar is available, measuring the wind coherence becomes more challenging and only the along-beam coherence has been studied so far [12,13]. We present hereby a novel measurement set-up based on a single scanning pulsed Doppler wind lidar to measure lateral and vertical wind coherence of the along-wind component. A WindCube 100S, deployed at an altitude of 25 m at the FINO1 platform in the North Sea, was used during one week in December 2015 for this purpose. Application of wind lidar technology to monitor the wind field near FINO1 is not new, as highlighted by e.g. [14–17]. However, this is the first time that such configuration provides both a temporal and spatial resolution high enough to explore the single and two-point statistics of the along-wind turbulence, for cross-flow separations that cannot be covered by the traditional wind masts.

The main goal of the present study is to assess the potential of a single Doppler wind lidar to measure wind coherence. In the following, the configurations and working assumptions are discussed first. Some preliminary results are then given, demonstrating the proof of concept. Finally, the root-coherence of the along-wind component is compared to semi-empirical models from the literature for different vertical and lateral separations.

2. Monitoring system and methods

2.1. Measurement site and instrumentation

Doppler wind lidars are remote sensing devices used for wind velocity measurement using Doppler frequency shift of light backscattered from aerosols. In the present study, a WindCube 100S from Leosphere is used. The instrument is a pulsed Doppler wind lidar with a rotating head enabling hemispherical scans. The word “scan” refers here to the sweeping process carried out continuously during 10-minutes by the lidar to record time series of the wind velocity. The WindCube 100S has been previously used as wind profiler [18], to study wind turbulence in complex terrain [11], or to monitor the wake of onshore wind turbines [19]. Two scanning patterns are hereby used: the Plan Position Indicator (PPI) and the Range Height Indicator (RHI) as highlighted by the schematic view in Fig. 1 where z is the vertical axis, x is the horizontal axis parallel to the wind direction, ϕ is the azimuth angle, α is the elevation angle, and r is the radial distance from the lidar. In Fig. 1, $\vec{t}$ is the unit vector tangent to the curve defined by the motion of the scanning head, and $\vec{n}$ is the unit vector normal to $\vec{t}$ and oriented towards the centre of the arc. The PPI scan is carried out for a fixed elevation, and multiple azimuth angles. The RHI scan is run for a single azimuth, and multiple elevation angles. If both the azimuth and the elevation angles are fixed, the lidar operates in Line Of Sight (LOS) mode. The azimuth angle is defined as the angle between the projection of the beam onto the horizontal plane and the North, whereas the elevation angle is defined as the angle between the beam and its projection onto the horizontal plane. The yaw angle β is defined as the angle between the wind direction and the azimuth angle, and consequently, a zero yaw angle indicates that the beam is aligned with the wind direction whereas a yaw angle of 90° indicates that the beam is perpendicular to the wind direction. The yaw angle β can be divided into two contributions: a yaw angle β_a introduced by an initial misalignment between the lidar beam and the wind direction, and a yaw angle β_s due to the sweeping of the beam around the mean wind direction during the PPI scan:

$$\beta = \beta_a + \beta_s \tag{1}$$

The research platform FINO1 is located to the north of Borkum (Germany) in the North Sea. As a part of the OBLEX-F1 campaign, a WindCube 100S was installed on the South-West part of the FINO1 platform in May 2015. In December 2015, exploratory tests were dedicated to coherence measurement by using PPI and RHI scans with configurations summarized in Table 1. The mean wind velocity and direction recorded by anemometers located at 33, 40, 50, 60, 70, 80 and 90 m above the sea and installed on a wind mast at the FINO1 platform are used as reference data. During the week studied, the Lidar was manually oriented to scan in PPI mode over a small sector centred on an azimuth of 211°, which was equal to the main wind direction according to the reference anemometers. For the RHI