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Measurement of wind profile with a buoy mounted lidar

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Abstract

Traditionally wind profile measurements for offshore wind farms have been obtained by using cup anemometers mounted on wind masts. This is a very expensive method to acquire wind profile data, and the wind data will also be influenced by distortion from the mast and the sensors. A much cheaper way of obtaining offshore wind data is using a buoy mounted lidar. In addition a buoy can also measure waves, current profile and other parameters.

To be able to measure the wind profile from a buoy, a ZephIR 300 lidar from Natural Power was mounted on a Fugro OCEANOR Wavescan buoy. The Wavescan buoy is specially designed for severe environmental conditions, and has been in operation world-wide since 1985.

The buoy system was tested off Titran off the island Frøya on the coast of central Norway. This is an ideal test site as it is in a very tough environment and near to a test centre for wind measurements with 3 instrumented met masts. The wind test centre is a part of the NOWITECH infrastructure programme. A reference lidar supplied by Natural Power was also located at the wind test centre. The distance between the reference lidar and the buoy was approximately 3.5 km. The Wavescan buoy was deployed for a period of one month during March-April 2012. The buoy lidar recorded 10 minutes average wind profile at 10 heights from 11.5 to 218m every third hour, while the reference lidar measured the wind at 53 m height continuously. During the measurement period the significant wave height varied between and 0.5 and 3.6m.

The wind speed from the buoy lidar has been compared with the reference lidar showing that there is practically no bias, while there is some scatter with a correlation coefficient (R^2) of 0.93. For higher wind speeds, which are mainly towards the coast, R^2 is 0.95 with a slighter larger bias. The scatter can be explained simply by the distance between the lidars, and that the reference lidar is located on land. We are therefore planning to compare the buoy mounted lidar measurements with closer offshore wind mast data.

Keywords: Wind profile measurement; lidar; buoy

1. Introduction

The interest for offshore wind farms is increasing due to increased demand of energy world wide and that climate change has increased the interest for renewable energy.

Reliable data of the wind profile for the relevant height of recent and future wind generators (30-300m) are important both for design, estimation of wind energy potential and during operations. As the power production of wind turbines increases with the 3rd power of the wind speed, accurate measurements of the wind profile is important both with respect to financing and profitability of the investments. Up to now such measurements have been carried out on bottom mounted met mast which is expensive and stationary. By measuring the measurements from a portable buoy the cost will be decreased by a factor 10 or more.

A research project was therefore initiated for development and demonstration of an autonomous system for measuring wind profile, waves and current profile from an anchored floating buoy.

The system should be able to measure wind profile in the region from 10-300 meters above sea level, relevant for actual and future offshore wind farms. Applications for such a measurement system include:

- Mapping of wind potential
- Optimisation of wind farm during operation
- Determination of structural loads and expected fatigue
- Validation of numerical simulations of the atmospheric and oceanic boundary layer
- Measurement of wake effect

The project included the following tasks:

1. Formulation of requirement and specification of the system
2. Concept study
3. Development of a prototype including hydrodynamic simulations
4. Development of a compensation algorithm for the buoy motion
5. Building of a prototype buoy
6. Field test of the buoy

The following institutions participated in the project: Fugro OCEANOR, Statoil, University of Bergen/Uni Computing, Christian Michelsen Research (CMR) and Marintek. The project has been funded by the Norwegian Research Council, Statoil and the participants as in kind contribution except for the work carried out by Marintek which was fully financed.

2. Lidar motion test

To examining the influence of wave motion on the lidar wind profile measurements, a motion test was carried out at the University of Agder, Grimstad autumn 2011. A motion platform was rented free of charge from the University in Agder, campus Grimstad, as this infrastructure was funded by NORCOWE. A motion sensor and sonic anemometer was also rented free of charge from NORCOWE. The motion platform used had 6 degrees of freedom, with the possibility of controlling frequency and amplitude individually. The motions along the following principal axis; roll, pitch, yaw, heave and surge, in addition to the combined motions; heave, surge and pitch were applied. The objective of the setup was to simulate actual wave motion.

ZephIR 300 from Natural Power and Wind Cube from Leosphere were included in the test, being continuous wave (CW) and pulsed lidars respectively. One of each type was mounted on the moton platform, while the other two were located at the ground as reference instruments. A picture of the test setup is shown in Figure 1.

Details regarding the test are given in [1].

Figure 1. Picture of test setup in Grimstad

3. Compensation algorithm

The compensation algorithm for motion corrections has been developed by Uni Computing, University of Bergen. The algorithm can use all the 6 degree of freedom data measured by the wave sensor in the buoy, to compensate the lidar wind measurements for the buoy motion. The algorithm uses the 1 sec data from the Wave sensor to compensate the 1 sec wind measurements at each height.

4. Description of the measurement system

The Wavescan Lidar buoy includes a ZephIR 300 lidar attached to the Wavescan buoy. Below is given a description of the different elements and the ant the assembling of the system.

4.1. The Wavescan buoy

The Wavescan buoy is Fugro OCEANOR's largest buoy well suitable for rough sea condition. The horizontal diameter is 2.8 m and the weight (without mooring) is approx. 925 kg. It has large buoyancy, 2800 kg, meaning that it is well able to withstand mooring load in deep waters.

The Wavescan buoy has a discus shaped hull that can be split in two to ease transportation. A keel with counterweight is mounted under the hull to prevent capsizing of the buoy.

A cylinder in the middle of the buoy hull contains all electronic modules, the power package and the wave sensor (integrated with the data logger). The instrument container has diameter 0.7 m and height 1.46 m, giving a volume of 0.56 m^3. The different electronic modules are mounted into special splash proof compartment boxes to secure safe handling of the sensitive electronics. The buoy is equipped with a mast to support the meteorological sensors and the antennae. The meteorological parameters are measured 3.5m above sea level. This version of the buoy has a modified design with larger solar panels with a capacity of 40W each.

The buoy hull includes wells for mounting different sensors.

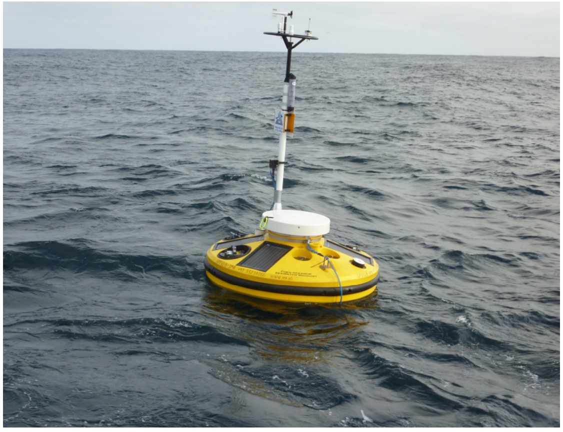
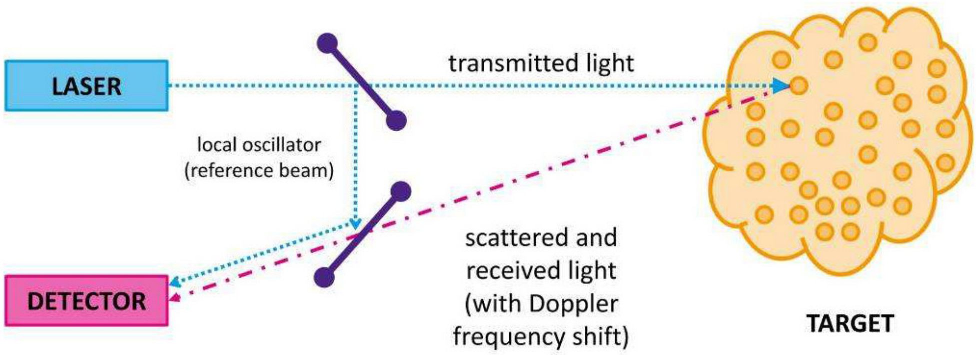


Figure 2. The Wavescan buoy. Picture of the buoy at the M-position obtained from University of Bergen.

4.2. The ZephIR lidar

ZephIR is a Continuous Wave (CW) lidar. The principle by which ZephIR measures the wind velocity is simple: a beam of coherent radiation illuminates the target (natural aerosols), and a small fraction of the light is backscattered into a receiver. Motion of the target along the beam direction leads to a change in the light's frequency via the Doppler shift. This frequency shift is accurately measured by mixing the return signal with a portion of the original beam, and sensing the resulting beats at the difference frequency on a photo detector. The essential features are readily seen in the simplified generic CLR depicted below.



CW systems are the simplest form of Lidar and possess the advantage of reduced complexity and high reliability for long periods of autonomous and remote operation. A CW system is physically focused to the required range and it is essentially the tightness of that focus that determines the probe length: the shorter the range, the smaller this length. The latest version of ZephIR has an effective probe length of ±1m, ±6m and ±15m at 40m, 100m and 150m ranges respectively. ZephIR can measure to a minimum range of 10m or shorter if required. Wind profiling is achieved by focusing at a number of chosen ranges in turn.

As a result of physically focusing the laser at each height of interest ZephIR achieves comparable sensitivity at each height: a critical design parameter for deployments in clean air with low concentrations of natural aerosols. CW lidar is highly sensitive and, as a consequence, it can achieve an acceptable signal-to-noise ratio in a much shorter timescale than other lidar methods.

ZephIR scans its beam in a 30 degree cone and continuously gathers 50 independent line-of-sight wind speed measurements per second, from which the wind vector is derived. The rapid data rate opens up possibilities for examination of detailed flow and turbulence across the measured disk. In addition, the velocity resolution of ZephIR is very high and its accuracy is measured to be 0.003m/s against a calibrated moving belt target.

Figure 3. The ZephIR 300 lidar

5. The SEAWATCH wind lidar buoy

SEAWATCH Wind Lidar buoy consists of a standard Wavescan buoy with the ZephIR 300 mounted on the lifting ring on the central cylinder as shown in Figure 4. For measuring the current profile an Aquadop Profiler from Nortek mounted in one of the wells can be included. The laser head is located 2.5m above the sea level, so the lowest measurement height for the lidar is 12.5m. In addition a wind sensor is included on the lidar 2.5m above the sea level and a standard wind sensor mounted on the top of the met mast 3.5m above the sea level.

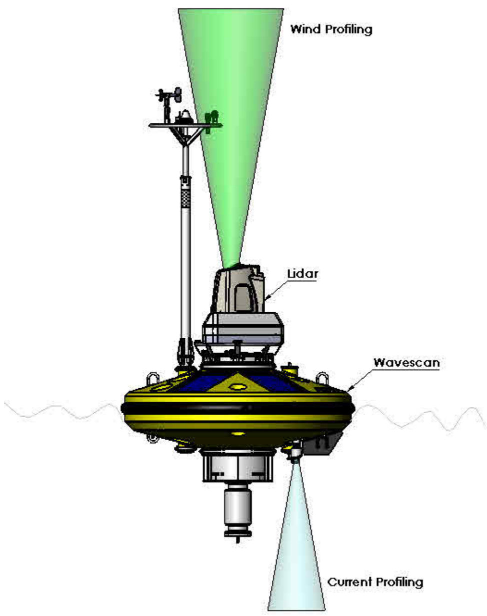


Figure 4. SEAWATCH Wind Lidar buoy with Nortek Aquadopp Profiler

6. Field test

The field test was carried out off Titran at the island Frøya, see Figure 5. This is an ideal test site since it is an exposed location and near a wind test centre with 3 instrumented met masts. The wind test centre is a part of the NOWITECH infrastructure programme. A reference lidar supplied by Natural Power was located at the wind test centre. The reference lidar is shown in Figure 6.

The Wavescan buoy with the ZephIR lidar was deployed 24 March 2012 and was recovered 19 April 2012. A picture of the buoy is shown in Figure 7**.** The distance between the reference lidar and the buoy was approx. 3.5km The buoy lidar recorded 10 minutes average wind profile at 10 heights from 12.5m to 218m every third hour, while the reference lidar measured the wind at 53 m height continuously. In addition the buoy measured waves and wind and humidity at the buoy met mast every 30 minute.

Figure 5. The location of the field test

Figure 6. The ZephIR reference lidar

Figure 7. The Wavescan buoy with the ZephIR lidar off Titran

Time series of wave height is presented in Figure 8. The significant wave height was largest during the first part of the test and reached a maximum of 3.5m on the 28th March. The wave height was below 1m after 9th April.

Time series of wind speed at 53m both for the buoy mounted and reference lidar are presented in Figure 9. As for waves the wind speed is strongest before 5th April with a maximum wind speed of 20m/s. After 5th April the wind speed is mostly below 10m/s i.e. fresh breeze (B5). The wind direction measured by the Gill ultrasonic wind sensor located on the buoy met mast 3,5m above sea level is given in Figure10. The wind direction was mainly between south-west and north until 8th April, and after then the wind direction was mainly between north and east i.e. offshore wind.

The wind speed at 3 heights measured by the ZephIR on the buoy is presented in Figure 11. There are some gradients at strong winds at the beginning of the measurement period, while there are small gradients after 1st April. During the first period the wind direction was from south-west with maritime polar air masses, while polar arctic air masses are present during northerly winds. These two air masses have different stability which will affect the wind profile. With northerly winds the air masses are transported over land over a distance of more than 3 km which has higher friction than air masses over sea, which may also affect the stability.

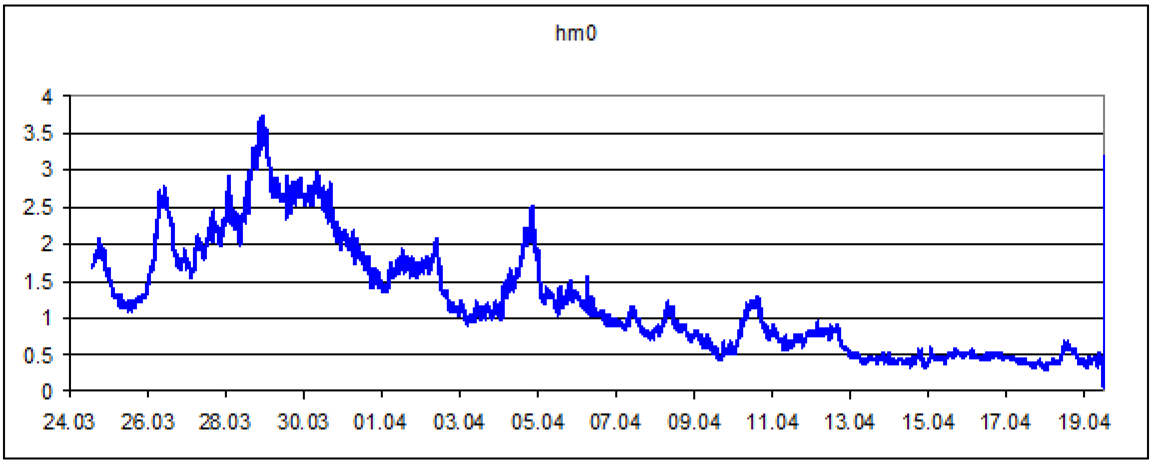


Figure 8. Significant wave height during the field test

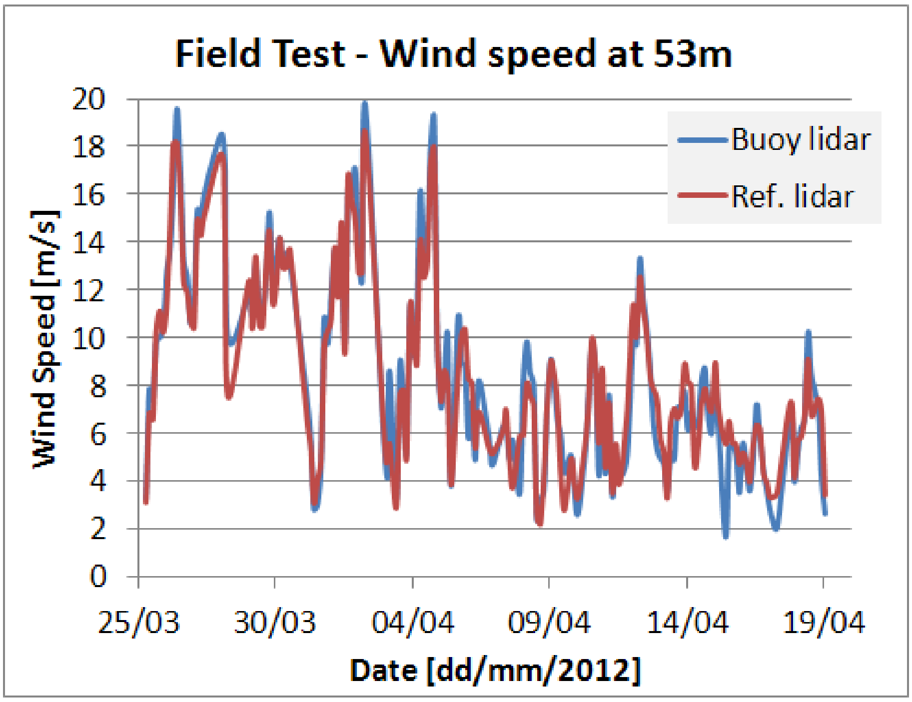


Figure 9. Time series from the onshore reference lidar and the buoy mounted lidar for the test period.

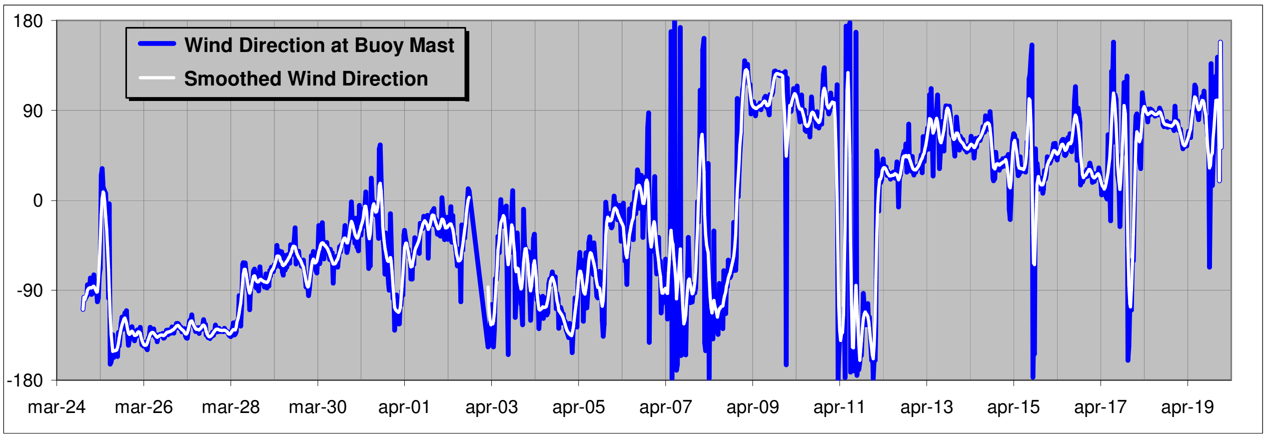


Figure 10. Wind direction measured by the buoy wind sensor 3.5m above sea level.

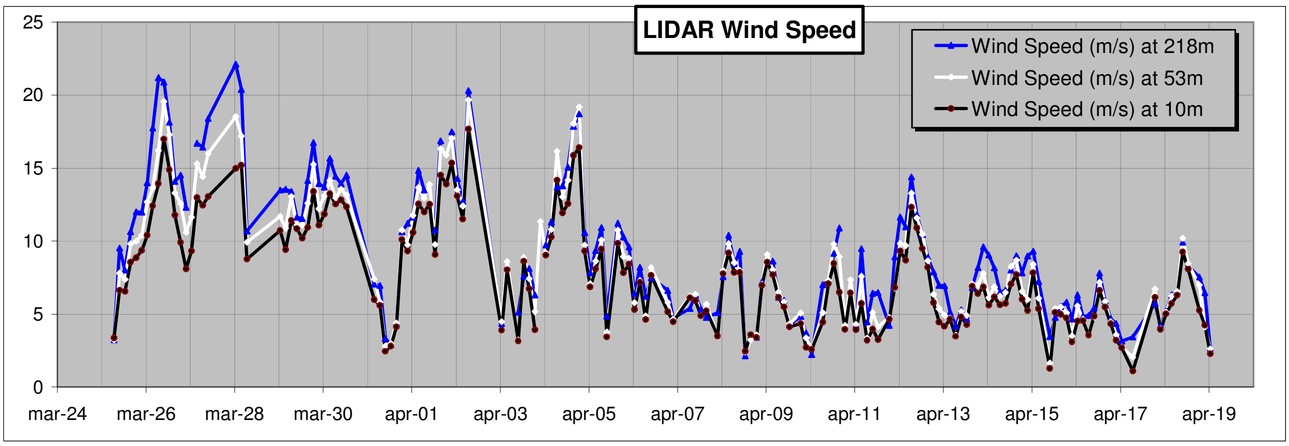
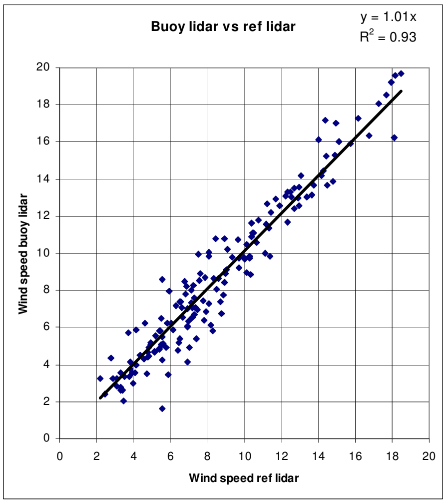


Figure 11. Wind speed at 10, 53 and 218m measured by the ZephIR at the buoy.

Scatter plot of the buoy lidar vs. the reference lidar is shown in Figure 12, which shows that there is practically no bias, while there is some scatter as indicated by a squared correlation coefficient of 0.93. Since the scatter is largest for small wind speeds, we have prepared a scatter plot for the period before 5th April. The scatter is then lower with a squared correlation of 0.95, while the bias is slightly larger. During the period after 5th April there is mainly offshore wind as discussed before, which may give larger gradients between the reference and buoy lidars.



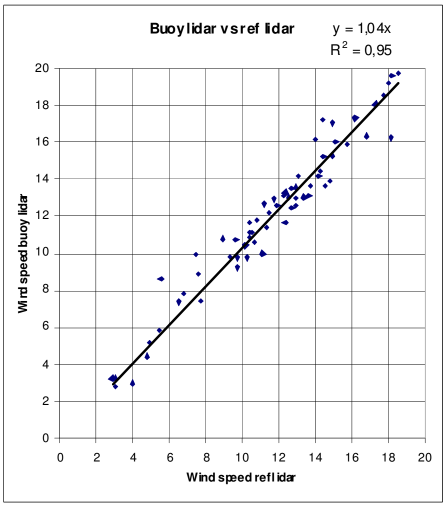


Figure 12. Scatter plot of the buoy mounted lidar vs. reference lidar for the whole period (left) and for the period before 5th April (right)

7. Conclusions

To be able to measure the wind profile from a buoy, a ZephIR 300 lidar from Natural Power was mounted on a Fugro OCEANOR Wavescan buoy. The Wavescan buoy is specially designed for severe environmental conditions, and has been in operation world-wide since 1985.

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Acknowledgements
Thanks to natural Power for supplying the reference lidar and to NOWITECH for getting access to the infra structure at the wind test centre at Titran.

References

[1] Jon Oddvar Hellevang**.** Effect of wave motion to wind lidar measurement - Comparison testing with controlled motion applied. Presented in this proceeding.