THE EFFECT OF MOTION ON CONTINUOUS WAVE LIDAR WIND MEASUREMENTS

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ABSTRACT

Robust and accurate wind measurement is required for offshore wind resource assessment, wind turbine power curve measurement and as a feed-forward input to wind turbine control systems. The use of floating and wind turbine mounted lidars is becoming more valuable as offshore wind resource exploitation increases and typical turbine hub heights get ever higher.

Doppler wind lidars measure the wind by detecting the line-of-sight Doppler shift caused by scattering of laser light from aerosols. Significant motion of the lidar affects the line-of-sight velocity and can lead to unreliable wind data. This poster contains numerical modelling of motion affected continuous wave (CW) lidar data and experimental measurements from buoy and wind turbine mounted lidars.

The results demonstrate that the exceptional sensitivity and high data rates of CW wind lidars mean that in many buoy mounted applications, high quality wind measurement can be carried out without compensation. In addition, turbine mounted CW wind lidars can carry out precise and accurate measurements if correction is made for nacelle inclination.

OBJECTIVES

- Illustrate how the motion of floating platforms such as buoys can affect the measurement of wind speed and direction by a CW Doppler lidar.
- Explained how wind turbine nacelle motion can influence a turbine-mounted lidar for power curve calculation and turbine control applications.
- Demonstrate regimes where motion compensation is unnecessary, and describe measurement and compensation strategies that can negate the effects of motion on CW wind lidar measurements.

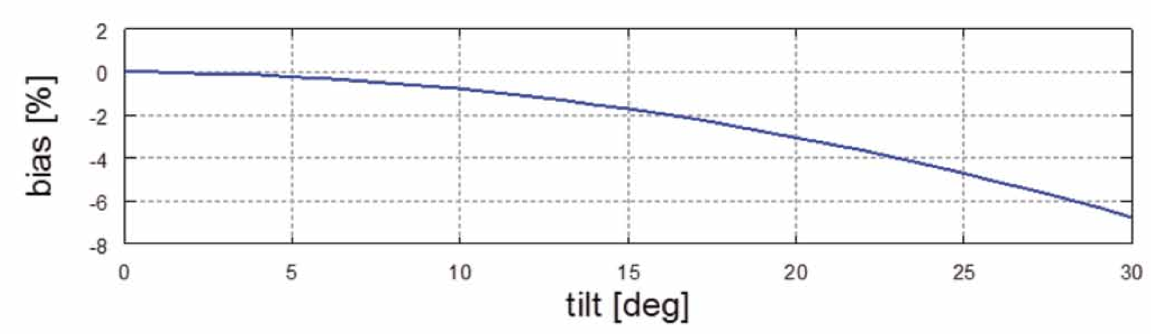
CONTINUOUS WAVE LIDAR WIND MEASUREMENTS

CW wind lidars focus a high power infrared laser at a specified measurement height or range. Light scattered by aerosols returns to the lidar and is analysed to determine its 'line-of-sight' Doppler shift. A series of measurements at different positions are used to reconstruct the wind field.

Since the laser in a CW lidar outputs a constant intensity, very high average powers are possible (>1 W) which results in exceptional sensitivity, and hence very fast measurement - typically 20 ms per data point, and 1 second per scan.

THE EFFECT OF BUOY MOTION

On a buoy, yaw will affect the wind direction measurement, whereas pitch and roll alter the laser line-of-sight and can cause a negative bias in wind speed measurement.



Typical buoy motions have a period of several seconds, so the high measurement rate of CW lidars effectively 'freezes' the motion for each measurement point (50 Hz) and adequately samples the motion for each scan (1 Hz)

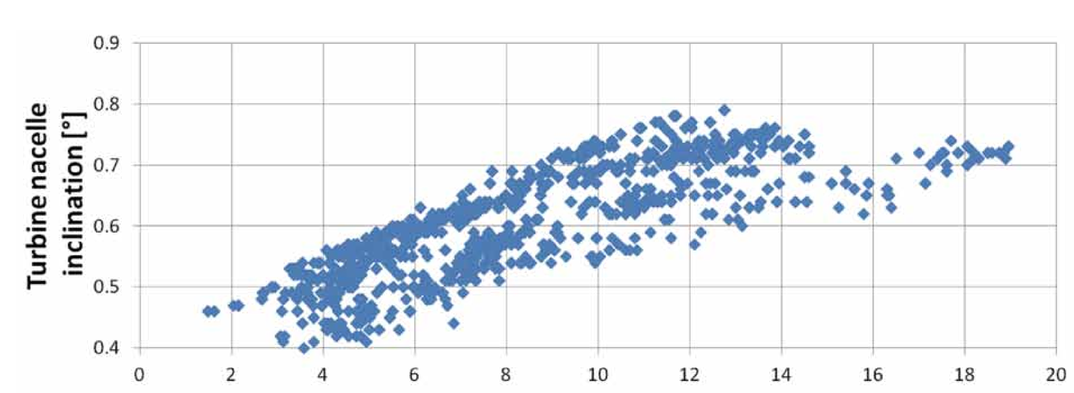
For a vertically pointing, buoy mounted lidar, surge and sway will generate a Doppler signal that adds to or subtracts from the true Doppler horizontal wind return, whereas heave will add to or subtract from the vertical wind component.

Studies carried out at Christian Michelsen Research AS, Norway, indicated that CW lidar is very robust to periodic motion as experienced by a buoy. Over an industry standard 10-minute averaging period, the effects were shown to average to zero and have very little effect [1].

THE EFFECT OF TURBINE MOTION

On a horizontally pointing, wind turbine nacelle mounted lidar, turbine 'nodding' (pitch) can add or subtract from the Doppler horizontal wind signal.

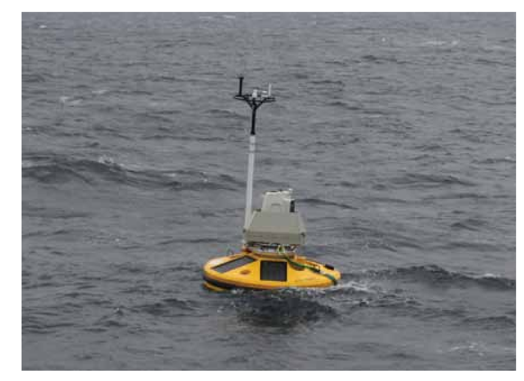
The highest velocity motion on a wind turbine originates from the small, low frequency vibration at the resonant frequency of the tower (typically 0.1 – 0.3 Hz). Turbine nodding can also affects the line-of-sight velocity, but in addition, it slightly alters the measurement height which can lead to errors in measurement interpretation [2].

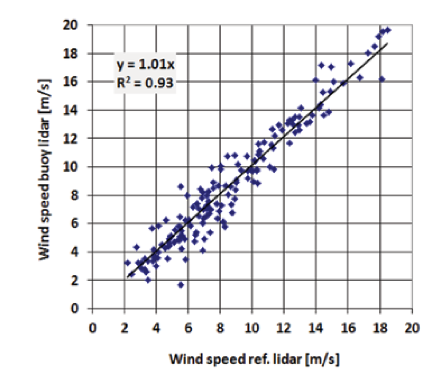


Similar to a buoy, the periodic nature of wind turbine nacelle motion causes the velocity component to average to zero over a 10-minute period. The wind induced tilt can be compensated by measuring the inclination and processing data appropriately for the measured geometry.

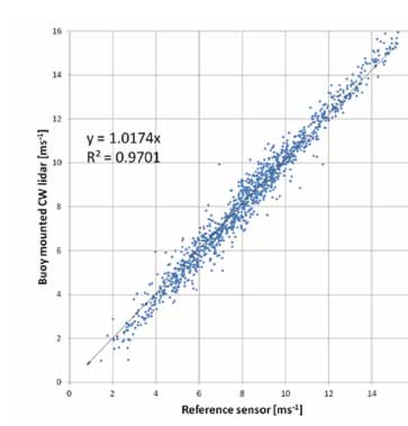
RESULTS

The following results demonstrate the small effect of buoy motion on CW lidar horizontal wind speed measurement. Below is a correlation plot measured on a small "wave rider" buoy in seas of significant wave height up to 3.5 m. The reference sensor was onshore in complex terrain at a distance of 3.5 km. It can be seen that the large motions experienced by this type of buoy (and the separation from the reference sensor) have resulted in reasonable precision, and the accuracy remains very high.

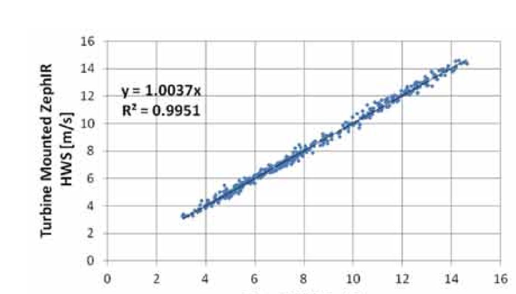


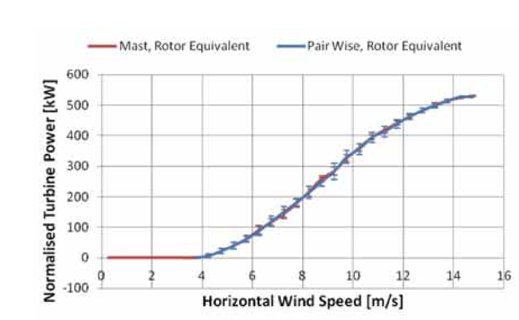


The following correlation plot was measured by a low motion, tethered buoy, the SeaZephIR, produced by SeaRoc. Here, pitch and roll motions are restricted to less than 5°, resulting in a precise and accurate comparison to a reference sensor, despite a separation of 3 km.



The plots below were obtained by comparison between a turbine-mounted CW lidar and a met mast at DTU Risø. The processing involved using only the parts of the scans that were located at cup heights. Inclination sensor data was used to account for both tilt and line-of-sight effects.





CONCLUSION

Continuous wave wind lidar can record accurate and precise horizontal wind speeds and directions while subject to motion:

- On larger buoys, no compensation is required.
- On smaller buoys, there is some loss of precision, but accuracy is maintained for 10-minute averaged data.
- For wind turbine mounted lidar, very high quality power curves can be measured if inclination is accurately measured and accounted for.

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REFERENCES

1. "The effect of wave motion on wind lidar measurements – comparison testing with controlled motion applied," JO Hellevang, Workshop on Remote Sensing Measurements for Renewable Energy, DTU Risø, Denmark, May 2012
2. "Nacelle lidar for power curve measurement," R Wagner and S Davoust, DTU Wind Energy E-0016, journal number 64009-0273, ISBN: 978-87-92896-3