# Lidar wind speed measurements from a rotating spinner

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## Introduction

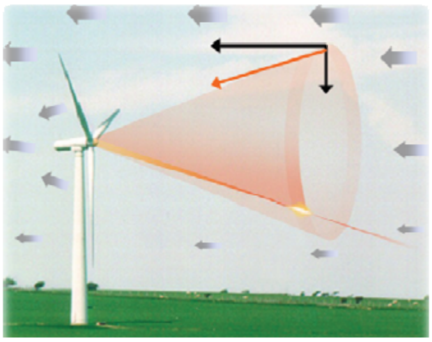

*Figure 1: Concept of measuring the upwind inflow conditions from a lidar integrated in the tip of a rotating spinner.*

Laser anemometry (lidar) is capable of making detailed measurements of the wind field approaching the blades of operational wind turbines. Incorporation of advance wind data into the turbine control system offers the possibility of improved energy yield and load reduction [1]. A turbine-mounted lidar capability was first achieved in a proof-of-principle experiment in 2003, in which a prototype ZephIR lidar was placed on the nacelle of a Nordex N90 turbine [2].

The lidar stared through the blades of the turbine and demonstrated the feasibility of accurate wind speed measurements at ranges up to 200 m in front of the turbine blades. Since then a number of different lidar devices have become available for use in the wind industry, all based on optical fibre and other components developed originally for the telecommunications industry. This approach has radically improved the cost, reliability and overall utility of lidar systems [3], and the technique now provides a genuine prospect for improvement of future turbine performance.

Here, we report our latest results from an experimental development in which a fast data acquisition continuous wave (cw) wind lidar (ZephIR) has been installed and operated in the rotating spinner of a large 80 m Ø, 59 m hub height wind turbine (Vestas NM80) located at Tjæreborg Enge in western Denmark. To the best of our knowledge we have achieved a “World first” successful operation of a forward looking wind lidar integrated in the spinner of an operating wind turbine. This new measurement concept has allowed an unimpeded view of the approaching wind field, which has been interrogated using several different scan patterns. Information on wind speed, shear and direction has been extracted and compared to the output from an adjacent met mast.

## Lidar in spinner: experimental setup

The lidar was mounted in the tip of the rotating spinner and aligned with the turbine shaft axis (cf. Fig. 1 and 2). On-line real-time data access and lidar control was enabled via wireless telecommunication, cf. the white antenna in Fig.2.

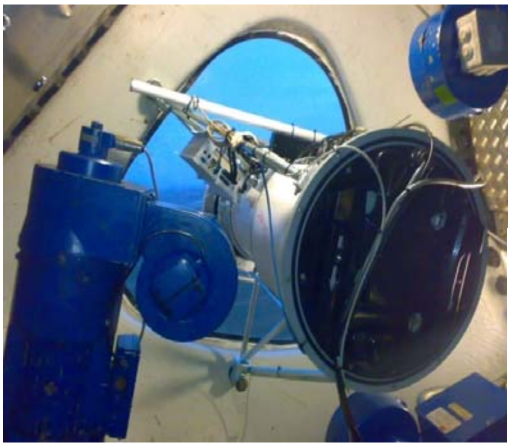

*Figure 2: The cw lidar installed on the turbine axis in the tip of the NM80 spinner. The lidar measures the approaching wind conditions by conical scanning with the laser beam through the window. Also seen are the three pitch control motors (blue).*

While the turbine was operating, the lidar's built-in wedge scanned the incoming wind field in circular scan patterns in the rotor plane 46 m and 100 m in front of the turbine, corresponding to 0.58 and 1.24 Ø rotor diameters upwind along the turbine shaft axis. The experimental setup was designed with scan cone half-angles of 15 degrees and 30 degrees in order to point and focus the lidar at the maximum lift 2/3 blade cord radius, corresponding to a distance along the laser beam to the focus point of 53 m with the 30 degree angle of the scanning cone and with 103 m distance to the focus point with the 15 degree cone, respectively. cf. Fig. 3.

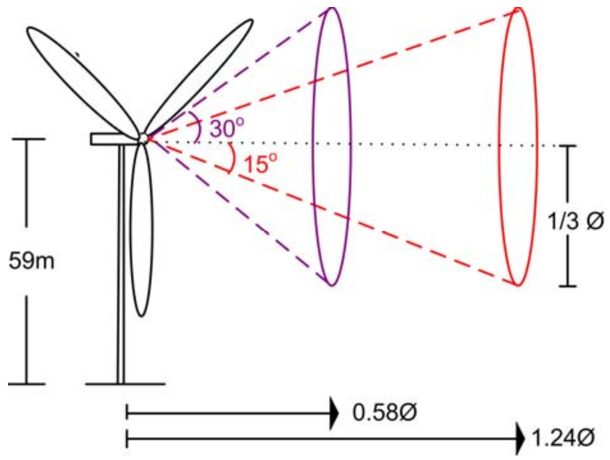


*Figure 3: Representation of the geometry of the measurements.*

The scan azimuth angle with respect to a fixed coordinate system is calculated from recorded information from the lidar's rotating wedge scanner and from measurements of the wind turbine's rotor position. With co-rotating wedge and rotor, a full 360 degree cone scan was performed in about 0.8 s while wind speed Doppler spectra were streamed at a rate of 50 Hz to a PC adjacent to the lidar. We estimate the cw lidar's radial measurement resolution to be about 20 m (full width half maximum) meters at the 103 meter range and about 5 m at the 53 m range [4]. The data have been post-processed to provide axial wind speed versus azimuth (scan) angle in non-rotating, fixed frames of reference.

## Results

Below are shown examples of lidar-measured wind speeds obtained from the azimuth scanning about the turbine axis. Data have been obtained in the rotor plane at the two investigated upwind distances located at approximately $\frac{2}{3}$ and at $\frac{4}{3}$ rotor diameter distances upwind respectively. Wind speeds are presented in polar plots and the lidar-measured radial wind speeds have been projected along the turbine axis under the assumption that the wind fluctuations are small compared to the mean wind speed.

The polar plots below show wind speeds obtained during the night of April 30, 2009. The boundary layer was strongly stratified and the turbulence was accordingly representative for stable atmospheric conditions with sporadic outbursts of intermittent turbulence.

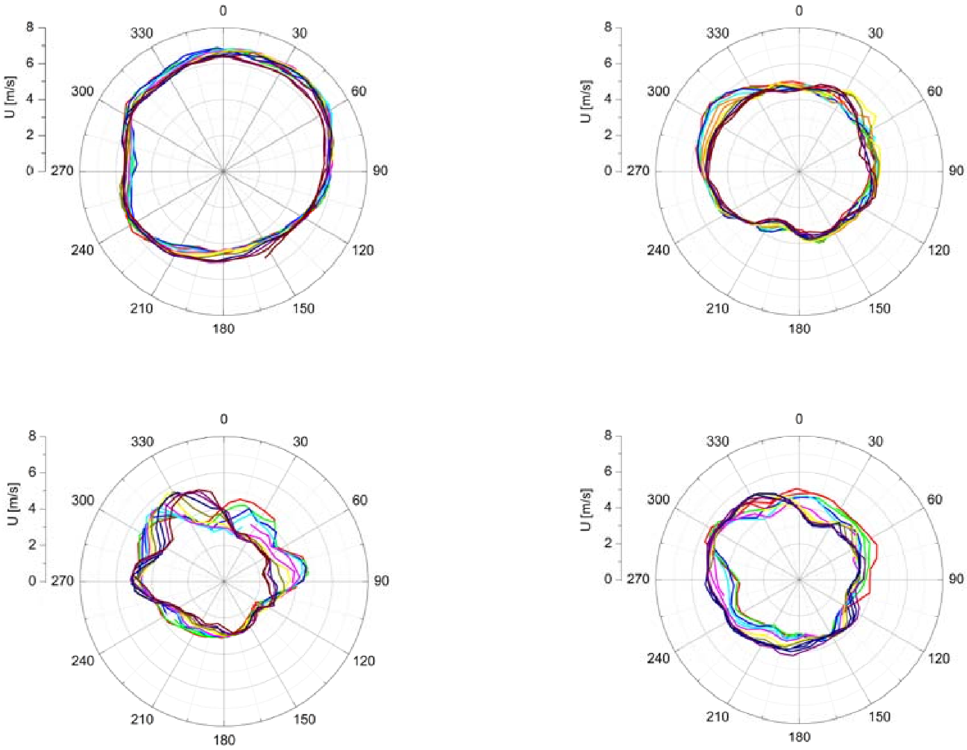


*Figure 4:* *Four examples of spinner-lidar measured upstream wind speeds during the early morning on April 30. 2009. Each of the four plots contain ten consecutive 360 degree scans of the wind speed measured remotely 100 meters in front of the operating turbine.*

The processed data in Fig. 4 show a high degree of variability in the approaching wind field encountered here during intermittent and stable stratified atmospheric conditions. The plots show lidar-measured radial wind speeds projected along the turbine axis. Each of the four plots show data from ten full 360-degree azimuth scans sampled during consecutive 8 s periods. These, to our knowledge “World first” new data show, not surprisingly, that the approaching wind field contain turbulent coherent structures, many of which with dimensions comparable to the rotor plane, which can prevail in time over several seconds. Assuming that the standard “Taylor’s frozen turbulence” hypothesis apply, this indicate that coherent structures in the turbulence will remain and impinge upon the rotating turbine blades a few seconds after they are detected. The mean wind speed during the April 30th experiment ranged between 5 and 8 m/s meaning that the measured turbulent structures should reach the turbine within a time span of 12 – 20 seconds later. Such lead time provide ample possibility for pitch control of the blades to mitigate fatigue effects from strong wind shear and yaw errors and also for optimising the power production via individual adjustments of pitch angles.

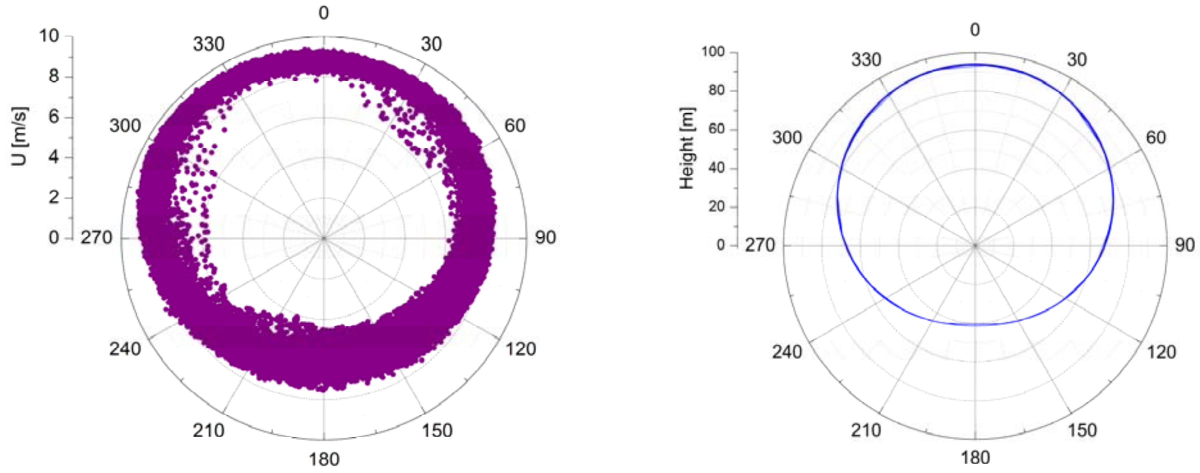


*Figure. 5: a) Spinner-lidar measured upwind wind speed sampled during a 10-min period. b) The lidar's measurement heights seen from the spinner window.*

Fig. 5 shows spinner-measured axial projected wind speeds measured in the rotor plane similar to the data in Fig. 4 from the night time experiment April 30. Here, however, we present all the wind speeds sampled over a full 10-min period. The measurements show that a strong vertical shear is present in the rotor plane, both with respect to direction and magnitude. Also the mean wind is not symmetrical in this case with respect to the turbine's vertical axis. It is furthermore evident that there is more turbulence near the ground in this April 30, 2009 stable stratified flow experiment.

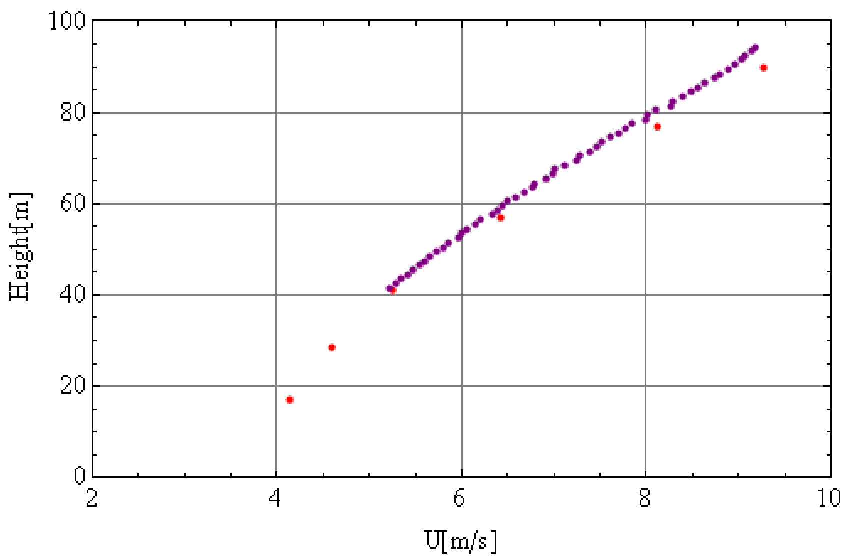


*Figure 6: Comparison of spinner-lidar measured (10 minute averages) vertical wind profile (purple dots) with data from a co-located adjacent instrumented met - mast (red dots).*

In Fig. 6 an inter-comparison between the vertical wind profiles measured by the spinner-mounted lidar and a co-located met-mast is shown. It is noticed that the wind profiles are approximately linear with height, which is indicative of a strong stable stratified mean wind flow.

The met mast was located approximately 300 meters downstream of the NM80 turbine during the night time data collection period of April 30. Therefore wake effects in combination with a low boundary layer mixing height could be seen in the vertical profiles. Nevertheless a relative good agreement was observed between lidar and met-mast observed wind speeds, in particular near hub height (59 m).

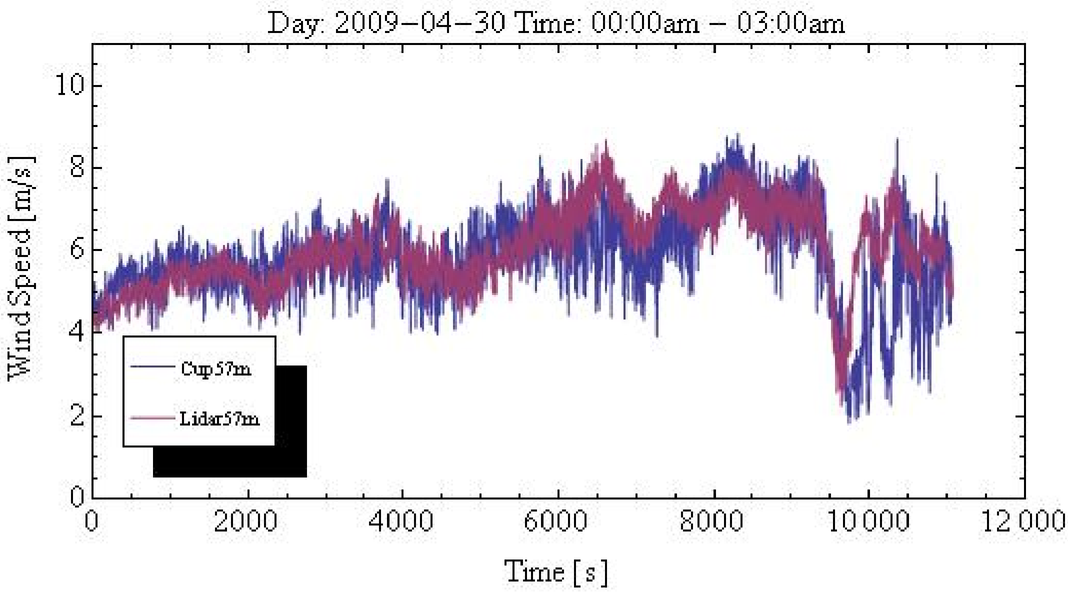


*Figure 7: Spinner-lidar measured of wind speeds near hub height (purple curve) inter –compared with cup anemometer measured wind speeds in the met mast during a 3 hour data sampling period during the night of April 30, 2009 (blue curve).*

In Fig. 7 we inter-compare 3-hours of wind speed measurements from the lidar with the corresponding measurements from a cup anemometer installed in the met mast close to hub height. The wind speed measurements are seen to correlate well the first 2½ hours before the wind speed drops and the wind direction changes such that it is likely that the met-mast is affected by a wake of a turbine. It can also be seen that the lidar captures less of the high-frequency variability due to the spatial filtering effects caused by the lidar's finite measuring volume [5,6].

**Perspective: Upwind lidar measurements integrated with active pitch control**

We have demonstrated that a contemporary spinner-mounted cw lidar can measure wind turbine axial wind components upwind at multiple sampling points distributed over the rotor plane of an operating wind turbine.

When combined with the control systems of the turbine, we envision that such measurements can provide real-time control data to the turbine's individual blade pitch control (IPC) systems, and in this way help compensate the effects of yaw errors and strong wind shear. We also envision that such wind data in combination with an active IPC system can help increase the power production of the turbine during sub-rated wind regime operation. This will be sought to be demonstrated in forthcoming experiments.

## Conclusions

We report what we believe are the first spinner-based lidar measured wind speeds sampled from the rotating frame of an operating wind turbines spinner. The "Tjæreborg Spinner-lidar Experiment" has demonstrated that a contemporary cw wind lidar (ZephIR) when mounted in the turbine spinner is able to measure the upwind approaching wind and turbulence structures from scanning the wind field about the turbine axis in real time. The spinner-integrated wind lidar system has shown excellent reliability and data availability was very high throughout the measurement period from the beginning of April through August 2009.

Our first results, including the aforementioned first analysis of the data from April 30, 2009 now further encourage more analysis of data already sampled during the Tjæreborg Spinner Experiment but also development and integration of cw wind lidar technologies in the area of active turbine control and improvement of wind turbine performance.

The next stages of development will involve further data analysis and also modelling and incorporation of lidar data as input to the wind turbine's yaw and pitch control systems, leading to a quantitative assessment of the potential for turbine performance improvement.

*Acknowledgement*:

***Mikael Rasmussen, Per Hansen, Dong Energy for access to the NM80 test Turbine at Tjæreborg, Vestas Winds Systems for safe operations in the NM80 Turbine. The experiment was performed as part of the new Danish research infrastructure facility activities under the auspices of Windscanner.dk*** **[7]*. Access to DONG Energy's NM80 Tjæreborg wind turbine and the local met-mast data has been facilitated in collaboration with the simultaneously ongoing DAN-AERO and TOPFARM test activities which is also gratefully appreciated.***

## References

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