COMPARISON OF LIDARS, GERMAN TEST STATION FOR REMOTE WIND SENSING DEVICES

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Summary

Deutsche WindGuard is involved in the test of lidar based wind measurement devices since 2005. At current status, there are two lidar systems commercially available, the British ZephIR and the French Windcube system. The Windcube has reached an excellent accuracy, reproducibility and availability in flat terrain, even at 135m measurement height above ground, while the ZephIR has problems to reach high accuracy in large measurement heights. The German Test Station for Remote Wind Sensing Devices has been initiated in order to provide the wind industry the possibility to have tested lidars or sodars prior to the application in the field, similar to cup anemometer calibrations. Furthermore, the test station is intended to be used for the type specific classification of remote wind sensing devices.

1 Introduction

Remote wind sensing by the use lidar (LIDAR=LIght Detection And Ranging) gets more and more intention by the wind energy industry. Results of the testing of the first commercially available lidar system (ZephIR) for wind engineering purposes have been presented [1] at the last DEWEK. Meanwhile, a major breakthrough has been gained by the introduction of a new lidar system, called Windcube. Detailed testing of the prototype of the Windcube and of first series models has been performed. In this frame, Deutsche WindGuard has set up the German Test Station for Wind Remote Sensing Devices.

2 The 2 Commercially Available Lidars

The two lidar systems commercially available today are briefly described in Table 1. Both lidar systems are ground based, small and compact and consists of standard telecommunications components (fiber lasers). At both systems, measurements of all three wind speed components are derived by rotating the laser beam on a cone.
The key difference is the determination of the measurement height. Zephir uses a continuous laser beam, while the measurement height is determined by focussing the beam on a certain height. After three rotations of the laser beam at a certain focus height (takes 3 seconds), the focus is shifted to the next height. By this, up to 5 measurement heights can be covered successively within about 16 seconds. At each focus height, the wind speed is measured at 50 azimuth angles.
In case of the Windcube, the measurement height is determined by range gates reserved for recording the backscatter (determination of elapsed time between sending and receiving the lidar beam). The rotation of the lidar beam is interrupted at each azimuth angle, and the measurements are taken at all measurement heights (up to 10 heights). Then, the laser beam is rotated to the next angle (4 angles per rotation). A full rotation takes about 6 seconds (4 second rotation is currently under test).

Feature	ZephIR	Windcube
manufacturer	Natural Power	Leosphere
determination of measurement height	focussing of lidar beam	time window
laser beam	continuous	pulsed
wave lengths	1.575 µm	1.54 µm
measurement heights	up to 5, compromising output rate	10
number of azimuth angles	50	4
cone angle	30°	30° (15° optional)
revolutions per measurement	3	1
output rate	1/3 Hz (1 height), 1/16 Hz (5 heights)	1/6 Hz (1/4Hz)
total weight	134kg	50kg
power consumption	100W, 24VDC	130W, 24VDC

Table 1: Comparison of key technical specs of ZepiHR and Windcube

3 Set-up of the Tests, German Test Station for Remote Wind Sensing Devises

3.1 Test of ZephIR
Detailed testing of the ZephIR has been performed against high quality cup and sonic anemometers at different masts with 65 m height and 124 m height from end of to 2005 to the beginning of 2006. Details of these tests are reported in reference [2]. All tests have been performed in flat terrain.

3.2 Test of Leosphere Prototype
Testing of the prototype of the Windcube has been performed by Deutsche WindGuard from February to

March 2008 against high quality cup anemometers at a 99 m high mast in flat terrain. Details of this test are reported in reference [3].

3.3 Test Station for Remote Wind Sensing Devices
So far 4 series models of the Windcube have been tested at the German Test Station for Remote Wind Sensing Devices since its founding in May 2008. The test station basically consists of a 135 m high met mast, which is kindly made available by the wind turbine manufacturer Enercon. The mast is directly located at the German North Sea Coast in flat terrain. The mast is heavily equipped with MEASNET [4] calibrated sensors, which are mounted according to IEC 61400-12-1 [5] (see sensor list in Table 2). All data is measured and stored with a rate of 5 Hz. A test pad for lidars is available directly adjacent to the mast, allowing easy and fast installation of lidar systems, convenient data transfer and the measurement of certain specs of remote sensing devices, like power consumption, temperatures etc. The mast allows using a very wide free measurement sector of 154°-318°, thus ensuring a fast coverage of a large wind speed range. Quite a variation of roughness conditions from sea surface roughness to open farm land and industrialised areas is present within the free measurement sector, what allows analysing remote sensing devices under different turbulence and wind shear conditions.

Measurement Height agl [m]	**Sensor**
135.1	2 cup anemometers Thies FC
132.6	cup anemometer Thies FC, 3D sonic Gill Windmaster
131.0	2 vanes Thies FC, air temperature, air pressure, air humidity
104.1	cup anemometer Thies FC, vane Thies FC, air temperature
71.7	cup anemometer Thies FC, 3D sonic Gill Windmaster vane Thies FC, air temperature
35.0	2 cup anemometer Thies FC, vane Thies FC, air temperature

Table 2: Specs of instrumentation of 135m-mast

4 Testing Results

4.1 Availability of Lidar Measurements
The ZephIR has reached a rate of valid data of 99.7 % at 65 m measurement height and 96.1 % at 124 m measurement height in respect to the horizontal wind speed component (wind speed and wind direction). The Windcube series models have reached availability levels of about 98 % at 100 m measurement height, 95 % at 150 m measurement height and 90 % at 200 m measurement height. These are remarkable results for remote sensing devices, taking into account the partly bad weather conditions during the measurement campaigns. Normally, even data periods with rain, snow or icing conditions had not to be filtered out.
Only the vertical wind speed component seems to be significantly disturbed by precipitation.

4.2 Horizontal Wind Speed Component
The ZephIR has reached a very good accuracy at 65 m measurement height when the so-called cloud correction has been applied (see reference [1], Figure 1). At 124 m measurement height, the ZephIR had the tendency to systematically underestimate the wind speed with increasing vertical wind shear [1]. This is believed to be due to the large focussing range of the ZephIR in large measurement heights. Different improvements in this respect are awaited, e.g. an optimisation of the cloud correction as is reported in reference [6].
The Windcube has shown a remarkably good and consistent accuracy in all tested measurement heights between 72 m and 135 m (Figure 2). It is noted that the Windcube does not provide measurement data below 40 m above ground. Furthermore, it is remarkable that all tested series models of the Windcube tested so far have shown a very consistent accuracy pattern (Figure 3). The software version delivered with the first series models had some deficiencies in the spectrum analysis, which has led to an overestimation in the wind speed range around 6 m/s of about 2 % (wind speed and direction dependent, see Figure 3). After implementation of an improved algorithm, the deviations of the Windcube to cup anemometer measurements is lower than the uncertainty of the cup anemometer measurements within the entire tested wind speed range (Figure 4).

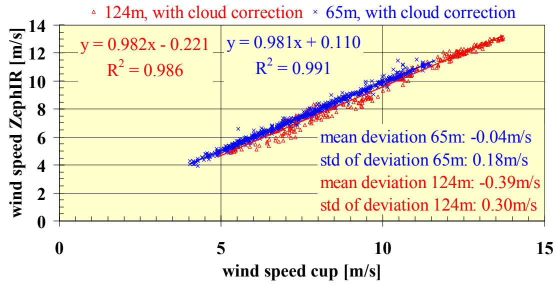

Figure 1: Comparison of 10-minute averages of horizontal wind speed component measured with ZephIR and with cup anemometers at 65 m and 124 m height with cloud correction applied.

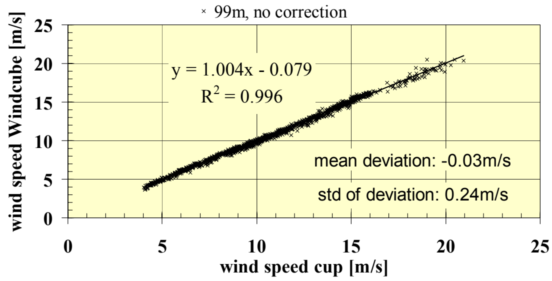

Figure 2: Comparison of 10-minute averages of horizontal wind speed component measured with the Windcube prototype and with a cup anemometer at 99 m height.

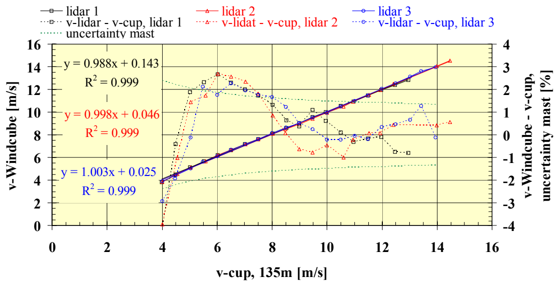

Figure 3: Comparison of 10-minute averages of horizontal wind speed component measured with 3 Windcubes and with a cup anemometer at 135 m height.

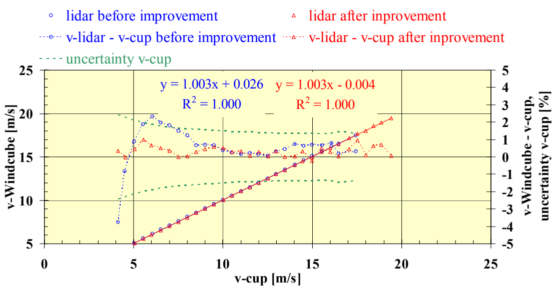

Figure 4: Comparison of 10-minute averages of horizontal wind speed component measured with a Windcube and with a cup anemometer at 135 m height before and after improvement of the spectrum analysis.

4.3 Wind Direction

The wind direction measurements performed by the ZephIR and by vanes correlate well in terms of 10-minute-averages (Figure 5). It has been found, that within 3-second averages sometimes the detected wind direction is switched around by 180°.

Also , the wind direction measurement performed by the Windcube works very well (Figure 6). Here, no disorientation of the wind direction at single 6(4)-second average has been found, what can be understood from the measurement principle.

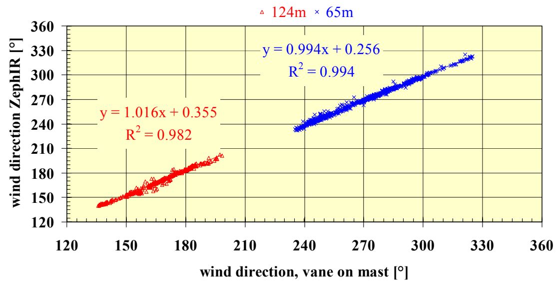

Figure 5: Comparison of wind direction measurement performed by ZephIR at 124 m and 65 m height above ground and by a vane (10-minute averages).

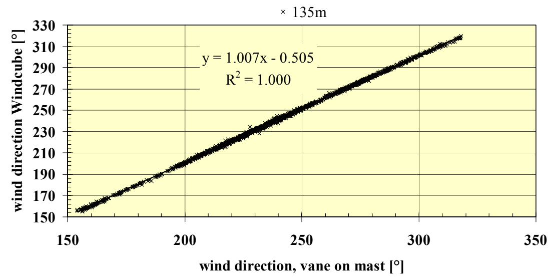

Figure 6: Comparison of wind direction measurement performed by Windcube at 135 m height above ground and by a vane (10-minute averages).

4.4 Comparison of Vertical Wind Speed Component

The vertical wind speed component as measured by the ZephIR and by the Windcube does not correlate well with the vertical wind speed component measured by sonic anemometers (Figure 7, Figure 8). The lidars need to be clearly improved in terms of the determination of the vertical wind speed component.

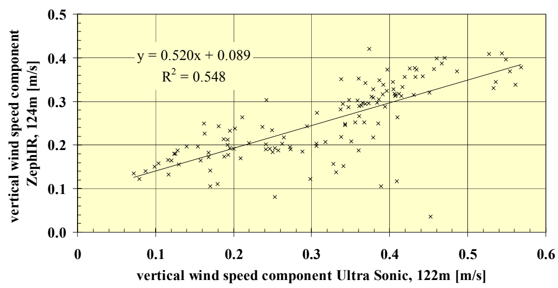

Figure 7: Comparison of vertical wind speed component measured at 124 m height above ground by ZephIR and measured at 122 m height above ground by an ultra sonic anemometer (10-minute averages).

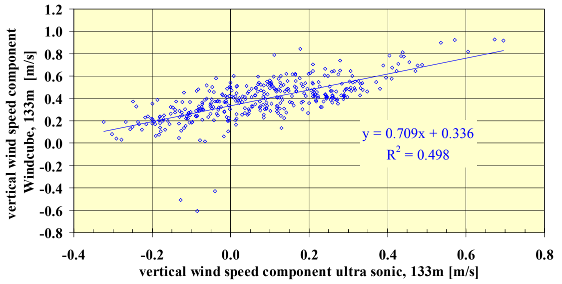

Figure 8: Comparison of vertical wind speed component measured at 133 m height above ground by Windcube and an ultra sonic anemometer (10-minute averages).

4.5 Comparison of Standard Deviation of Horizontal Wind Speed Component

The standard deviation of the horizontal wind speed component as measured by the ZephIR is smaller than measured by cup anemometers (Figure 9), what can is expected due to the spatial averaging of the lidar and the longer pre-averaging period of 3 seconds.

In contrast, the Windcube measures the standard deviation of the horizontal wind speed component astonishing well (Figure 10). Here the reduction of the cone rotation period from about 8 seconds at the prototype to about 6 seconds at the first series version to about 4 seconds in a testing mode has led to a small improvement.

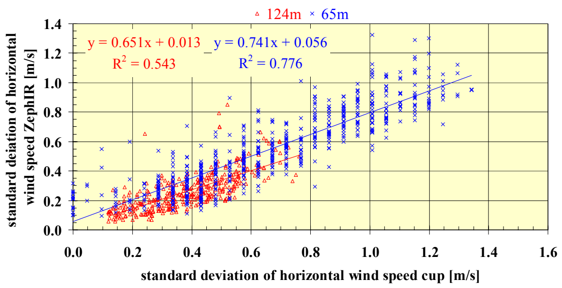

Figure 9: Comparison of standard deviation of wind speed within 10-minute periods as measured by ZephIR and cup anemometers at 124 m and 65 m height.

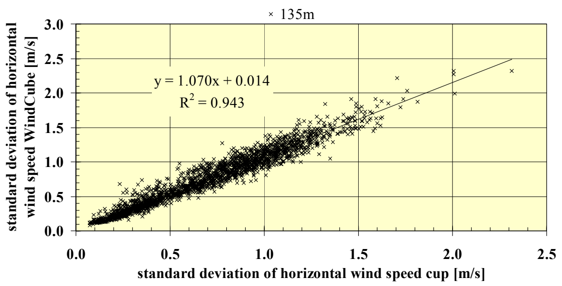

Figure 10: Comparison of standard deviation of wind speed within 10-minute periods as measured by Windcube and a cup anemometer at 135 m height.

4.6 Comparison of Extreme Values of Horizontal Wind speed Component

The maxima of the horizontal wind speed component within 10-minute periods measured by the ZephIR are underestimated compared to cup anemometer measurements, while the minima are overestimated (Figure 11). The origin can again be seen in the larger spatial averaging of the ZephIR and the larger pre-averaging period of 3 seconds.

The Windcube shows only a small overestimation/underestimation of the wind speed maxima/minima within 10-minute periods (Figure 12).

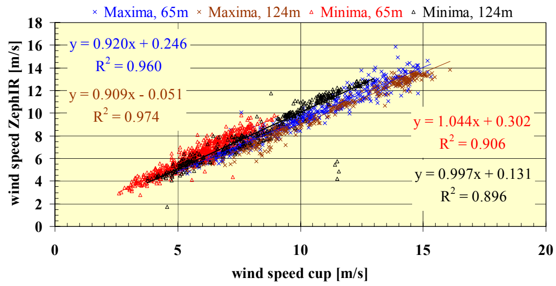

Figure 11: Comparison of extreme values of wind speed within 10-minute periods as measured by ZephIR and cup anemometer at 124 m and 65 m height above ground.

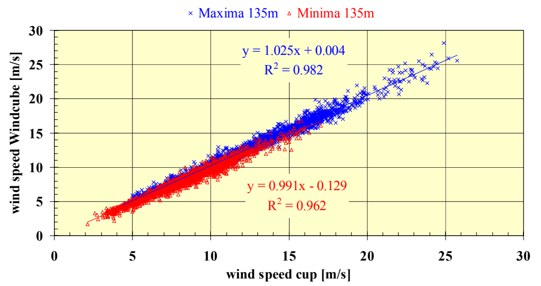

Figure 12: Comparison of extreme values of wind speed within 10-minute periods as measured by Windcube and a cup anemometer at 135 m height (4 second cone rotational mode).

5 Status of Remote Wind Sensing

From our view, remote wind sensing has reached the following status for applications in wind engineering:

- The Windcube has reached a high level of accuracy and reproducibility of measurements in flat terrain conditions. Measurements with this type of instrument are suitable for nearly all applications in wind engineering, including power curve measurements and site assessments (at least in flat terrain). This level of confidence has so far not been reached by sodar instruments (see also reference [7]).
- Individual testing of lidar and sodar units prior to the field application helps to identify system faults and to ensure the system accuracy. Furthermore, it helps to convince financing parties or investors of wind farms when using a remote sensing device for site assessment purposes. This is in line with a conclusion drawn by an expert meeting of

sodar and lidar experts organised by IEA in the beginning of 2007 [7].

- In complex terrain sites, the influence of the relatively large scanning volume of today's lidars and sodars must be carefully considered in terms of its influence on the measurement accuracy [8].
- We can report from our commercial activities that the application of lidar measurements for site assessment purposes onshore often struggles to be competitive to conventional mast based measurements at measurement heights below 100 m due to the high purchase cost of lidar instruments. Lidar measurements are economically very attractive for measurements above 100 m and for offshore applications. Furthermore, short lidar campaigns over typically 3 months measurement periods in combination with measurements over typically one year with smaller reference masts (e.g. 50-60 m) are a valuable solution for many site assessment purposes.

6 Acknowledgement

Thanks belong to Enercon to make available the 135 m met mast and a lot of technical support for the German Test Station Remote Wind Sensing Devices, as well as for the permit to use wind data from other masts for the reported work.

7 References

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