A Novel Lidar System – First Results of Highly Resolved Wind Vector Measurements

Harald Mueller (1), Michael Eggert (1), Christian Gutsmuths (1),
Axel Albers (2), Klaus Franke (2), Ailt-Wiard Janssen (2)

(1) Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany
E-Mail: harald.mueller@ptb.de, tel.: 0049 531 592 1310, fax.: 0049 531 592 691310

(2) Deutsche WindGuard Consulting GmbH, D-26316 Varel, Oldenburger Straße 65, Germany

1. Summary

Conventionally used wind Lidar systems are based on the monostatic Lidar principle by tilting one laser beam into different directions to determine a wind vector. These systems are well established and provide reliable measurement results especially for flat terrain with almost homogeneous wind fields. With increasing inhomogeneities in the wind fields wind vector measurements and their traceability become problematical. The newly developed bistatic wind Lidar allows wind vector measurements traceable to the SI units by determining the velocity vector of single aerosols in a highly resolved measurement volume in heights from 5 m to 250 m. By applying one transmitting beam and three receiving beams focussed into a well-defined measurement volume it is for the first time possible to perform traceable Lidar measurements of the wind vector with a high local resolution of less than 1 dm^3 and a resolution of 0.1 ms^{-1} for the wind speed. In contrast to conventional wind Lidar systems the newly developed bistatic wind Lidar system allows to measure wind vectors without any assumptions concerning the homogeneity of the wind field, so that environmental conditions have no influence on the measurement uncertainty and the traceability of wind vector measurements.

2. Introduction

Conventinal monostatic wind Lidar systems have a common transmitting and detection beam which is tilted into different directions to determine the wind vector provided that the wind field is almost homogeneous (fig. 1 left side). Leaving flat terrain and having to consider inhomogeneous wind conditions predominating in complex terrain (fig.1 right side) significant errors for the measured wind speed in the range of 10 % cannot be excluded [1].

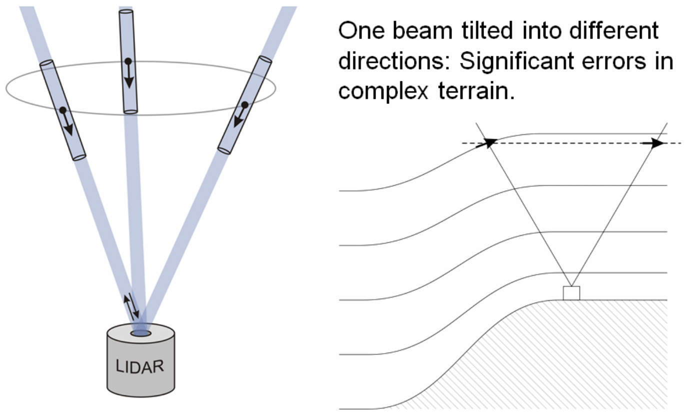


Figure 1: Working principle of monostatic Lidar systems and potential influence by complex terrain

Thus in the case of unidentified and complex wind fields the accuracy and traceability of monostatic Lidar measurements become questionable without considering any other reference measurements. For instance the IEC 61400 12-1 provides in its annex L in relation to wind turbine power curve testing only deployments where a remote sensing device is monitored by a calibrated cup anemometer mounted on a mast and in case of power performance assessments a limitation to flat terrain [2].
The aim of the novel Lidar system development is to overcome the present limitations given by the working principle of monostatic remote sensing devices requiring almost homogeneous wind fields. The basic idea of the novel system relies on the use of one transmitting laser beam and three detection beams in order to determine the three components of the wind vector simultaneously in a highly resolved measurement volume (fig. 2).

Depending on the adjusted measurement height ranging from below 10 m up to over 200 m the measurement volume diameter varies in the range from below 1 mm up to approximately 1 cm and the measurement volume length from below 1 cm up to 2,5 m for the currently realized measurement set-up with the three detection units sited with a radius of 1m around the transmitting unit.

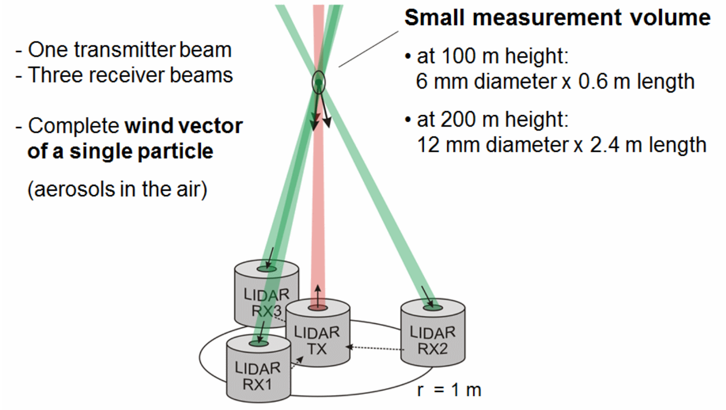


Figure 2: Working principle of novel bistatic Lidar systems with high local resolution

Based on the working principle and the well defined geometry of the measurement set-up, the exactly determinable measurement height of the highly resolved measurement volume, the known laser wavelength and the precise frequency measurement of the Doppler shifted laser light scattered by aerosols, the novel bistatic Lidar allows to perform temporally and locally highly resolved wind vector measurement traceable to the SI units without any requirements on wind conditions in the field.

3. Set-up of the bistatic Lidar system

The novel bistatic Lidar system comprises a narrow-bandwidth master laser and a high power erbium doped fiber amplifier to generate the transmitted light at 1550 nm. While monostatic systems typically use combined transmitting/receiving optics and an optical circulator to separate the received light scattered by particles, the bistatic system is based on discrete transmitting and receiving optics (fig. 3). In order to focus the beams of the transmitting and the receiving optics into a small measurement volume, all four optics are motor controlled. An optical time of flight measurement is used to superimpose all three receiving beams with the transmitting beam in a selected measuring distance between 5 m and 250 m. Correlation techniques between the three detection channels are applied to ensure that the wind vector measurement is based on the evaluation of the detected scattered light signals stemming from one and the same single particle in the measurement volume respectively.

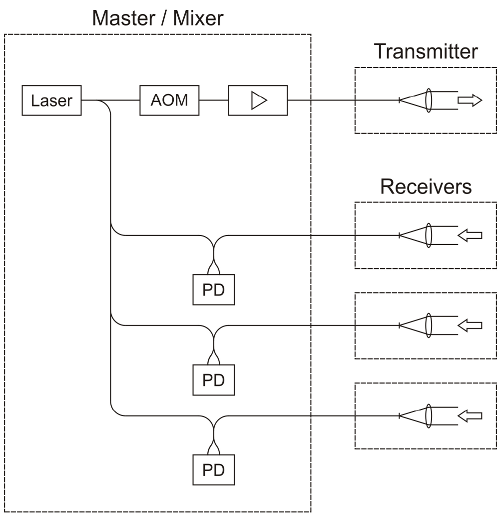


Figure 3: Set-up of the bistatic Lidar system developed by PTB

To ensure a mobile operation with stable working conditions in the field, especially with respect to requirements on the mechanical set-up and the optoelectronics, the bistatic Lidar system has been enclosed in a temperature controlled housing mounted on an air suspended trailer (fig. 4).

Figure 4: PTB trailer with the prototype of the bistatic Lidar and view onto the set-up inside the housing

First in the field measurements of the novel bistatic Lidar prototype have been performed within the scope of two measurement campaigns on the wind energy test field of the Deutsche WindGuard Consulting GmbH near Aurich in Northern Germany.

4. First measurement results

In the scope of the first validation tests the results of the bistatic Lidar measurements were compared with the met mast measurements on the wind energy test field of the Deutsche WindGuard. For this the measurement data of the met mast taken by cup anemometers in the heights of 135 m and 100 m (fig. 5: level 1 and level 3) including the corresponding wind vanes were taken as reference data.

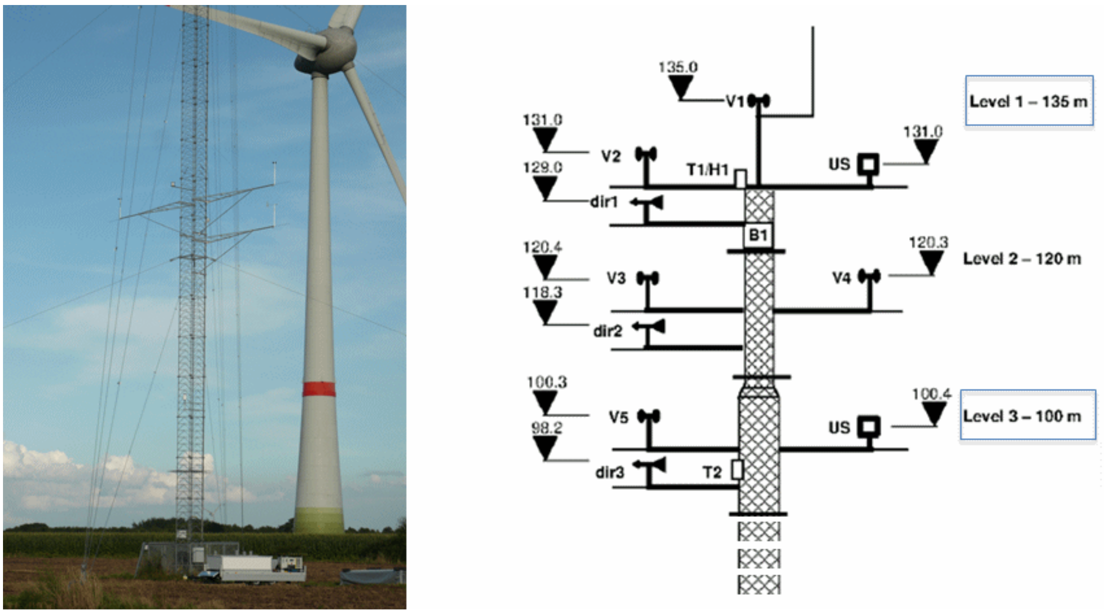
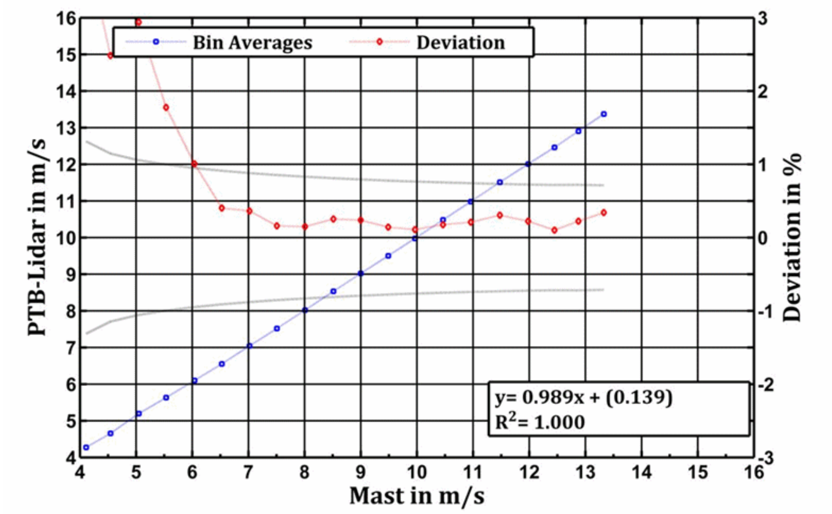


Figure 5: PTB trailer with the prototype of the bistatic Lidar on the test field of the Deutsche WindGuard and outline of the three upper measurement height levels of the 135 m met mast

Of particular interest for the validation of the novel bistatic Lidar is the comparison of the mast top cup anemometer data with the Lidar data for the same height nearby the center of the mast, as the single top-mounted anemometer constitutes the ideal configuration to achieve negligible flow distortion of the wind speed measurements. In the data evaluation the local distance between the top mounted cup anemometer and the position of the Lidar measuring volume is considered by correlating the time resolved wind speed data.

The evaluation of the wind speed data measured over a period exceeding 24 hours shows a deviation of the top-mounted cup anemometer and the bistatic Lidar data of less than 0,5 % over the velocity range from 6,5 m/s to 13 m/s (fig. 6). Thus the determined deviation lies within the calibration uncertainty of the cup anemometer used as reference.



(Measurement period: 28 h, evaluation time intervall:1s, time delay: distance correlated 1,1s)

Figure 6: Comparison result of novel PTB-Lidar and mast top mounted cup anemometer data, measurement height: 135 m; blue line: wind speed PTB-Lidar versus wind speed met mast; red line: deviation between PTB-Lidar and met mast measurement in %; grey line: uncertainty of the met mast measurement in % (k = 2)

Altogether the comparison result compressed in figure 6 represents a very promising first validation result for the novel bistatic Lidar system. In addition to the met mast data one of the measurement campaigns contained also data of a monostatic WINDCUBE Lidar.

In the following the met mast data derived from the corresponding calibrated cup anemometer were used as reference data; the measured horizontal velocities from the met mast and the two different Lidar systems were synchronized; mean values were calculated over discrete periods of 10 minutes and segmented into 0,5 m/s bins to be compared with each other within each bin. The results for the 10 minutes mean values over a measuring period of over 24 hours with almost undisturbed wind conditions are represented in figure 7.

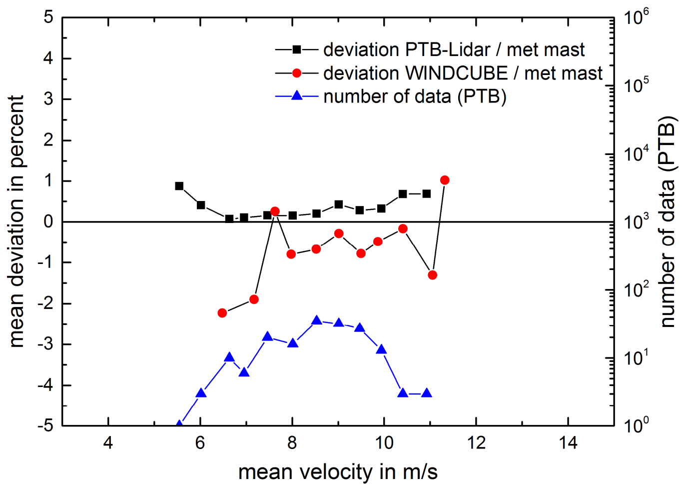


Figure 7: black dots: deviation between bistatic PTB-Llidar and met mast, measuring height: 135 m; red dots: deviation between monostatic WINDCUBE and met mast, measurement height: 135 m, distance between WINDCUBE and met mast: 50 m; blue dots: number of data of the bistatic PTB-Lidar; all values are mean values of 10 min time slots

For velocity bins including 10 or more mean values, the deviation between the bistatic PTB-Lidar and the top mounted cup anemometer data were again below 0,5 %. In the same velocity range the deviation between the conventional monostatic Lidar data and the top mounted cup anemometer data was also below 1 %.

The situation for the monostatic Lidar located in a distance of 50 m from the met mast changes, if we look at temporally higher resolved mean values based on the data taken second by second. Considering now the mean values resulting from time slots over 1 second the deviation between the bistatic Lidar and the top mounted cup anemometer again is below 0,5 % between 6,5 m/s and 13 m/s while the deviation between the cup anemometer and the monostatic Windcube data increases noticeably caused by ordinary gusts of the undisturbed wind field (fig. 8).

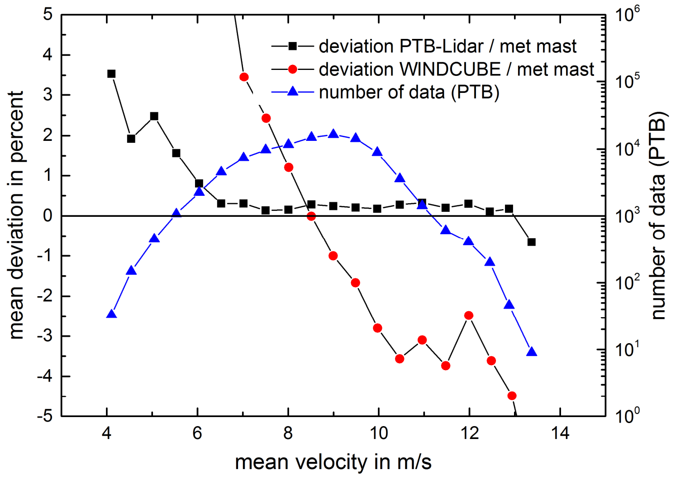


Figure 8: black dots: deviation between bistatic PTB-Lidar and met mast, measuring height: 135 m; red dots: deviation between monostatic WINDCUBE and met mast, measurement height: 135 m, distance between WINDCUBE and met mast: 50 m; blue dots: number of data of the bistatic PTB-Lidar; all values are mean values of 1 s time slots

The evaluation of the simultaneously recorded wind speed data from the montostatic Lidar, the bistatic Lidar and the top mounted cup anemometer illustrate a high consistency of all the data if we look at mean values resulting from time slots of 10 minutes as specified in the IEC 61400 12-1 standard. Analyzing the data from time slots with the higher resolution of 1 s only the bistatic Lidar measurement results show a remarkable consistency with the cup anemometer measurements which is indicated by deviations below 0,5 % independent of the selected time slot duration.

Even for disturbed flow conditions in the wake of a wind turbine the deviations of the bistatic Lidar and the cup anemometer data were below 1 % considering 1 s time slots over a period of 15 h (fig. 9).

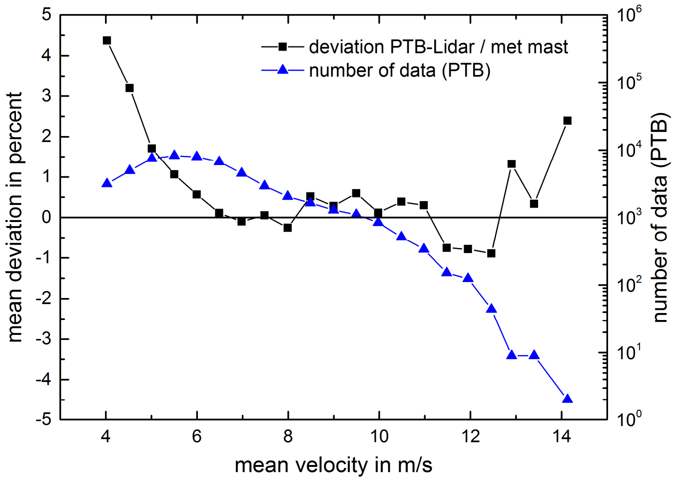


Figure 9: black dots: deviation between bistatic PTB-Lidar and met mast, measuring height 100 m; blue dots: number of data of the bistatic PTB-Lidar, measuring height 100 m; disturbed flow; all values are mean values of 1 s time slots

6. Future development steps

Besides further investigations and measurement campaigns for the analysis and validation of the novel bistatic Lidar system the current and future focal point consists in the further development of the hard and software in order to ensure a full autonomous operation of the bistatic Lidar system in the field.

7. Conclusion

First validation tests of the novel PTB bistatic Lidar system for wind vector measurements by comparison measurements with a met mast already show a comparability of measurement results within a few per mill. Based on the well-defined geometry, the known wavelength and precise frequency evaluation, the novel system has the potential for traceable wind speed measurements in flat as well as in complex terrain.

Due to its unique characteristics the novel bistatic Lidar system is predestinated to be applied in current research and development activities to improve the measurement capability and accuracy for site and wind resource assessment, power curve measurement, flow modelling as well as classification and calibration of conventional Lidar systems.

8. References

[1] Bingöl, F.; Mann, J. & Foussekis, D. "Lidar performance in complex terrain modelled by WAsP engineering", Chapter in EWEC 2009 Proceedings online, EWEA, 2009

[2] CDV IEC 61400-12-1 Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines