Adv. Sci. Res., 12, 85–89, 2015
www.adv-sci-res.net/12/85/2015/
doi:10.5194/asr-12-85-2015

Advances in Science & Research
Open Access Proceedings

14th EMS Annual Meeting & 10th European Conference on Applied Climatology (ECAC)

Lidar uncertainty and beam averaging correction

A. Giyanani, W. Bierbooms, and G. van Bussel

Wind Energy Research Group, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629HS Delft, the Netherlands

Correspondence to: A. Giyanani (a.giyanani@tudelft.nl)

Received: 5 January 2015 – Revised: 7 April 2015 – Accepted: 7 April 2015 – Published: 13 May 2015

Abstract. Remote sensing of the atmospheric variables with the use of Lidar is a relatively new technology field for wind resource assessment in wind energy. A review of the draft version of an international guideline (CD IEC 61400-12-1 Ed.2) used for wind energy purposes is performed and some extra atmospheric variables are taken into account for proper representation of the site. A measurement campaign with two Leosphere vertical scanning WindCube Lidars and metmast measurements is used for comparison of the uncertainty in wind speed measurements using the CD IEC 61400-12-1 Ed.2. The comparison revealed higher but realistic uncertainties. A simple model for Lidar beam averaging correction is demonstrated for understanding deviation in the measurements. It can be further applied for beam averaging uncertainty calculations in flat and complex terrain.

1 Introduction

Lidar is an acronym for light detection and ranging. Lidars are laser based systems working on principles similar to that of Radar or Sodar, see Boquet et al. (2011). There have been studies performed to validate the Lidar with metmast sensors by Smith et al. (2006), Lang and Mckeogh (2011), Westerhellweg et al. (2010) and more. In this study, the aim was to extend the filtering criteria to include the Lidar CNR, availability and Lidar's sensitivity in foggy and rainy conditions.

Albers et al. (2009), Lindelöw-marsden (2009) and Albers et al. (2012) have worked extensively on evaluation of uncertainty in wind speed measurements with Lidar. This study aimed at identifying the sources of deviations in the measurements and quantifying the uncertainty in wind speed. Thus, significant atmospheric variables can be considered for inclusion in the CD IEC 61400-12-1 Ed.2, see Albers et al. (2012).

Lidars can detect wind speed without getting affected by the metmast and wake shadowing, one of the reasons is due to averaging of the 4 lidar beams separated spatially into one measurement. This study was aimed at evaluating the effects of Lidar beam averaging on wind speed measurement which can be further used for uncertainty calculations. A simple model for Lidar beam averaging is discussed here. These understandings would help the inclusion of Lidars and their appropriate uncertainties for the reference wind speed measurement into the power curve standard CD IEC 61400-12-1 Ed.2, IEC (2005).

2 Site and data description

2.1 Site description

The site considered for the comparison is the ECN wind-turbine test site at Wieringermeer, EWTW in North Holland as shown in Fig. 1. The test site is characterised by flat terrain, consisting mainly of agricultural area with single farm-houses and rows of trees. The lake IJsselmeer is located at a distance of 2 km East of metmast 3, MM3 (Lat: 52°50′ N, Lon: 5°5′ E). The data from MM3 and the two ground based vertical scanning Lidars are considered for the comparisons which is calibrated and installed using the IEC and Measnet guidelines, see IEC (2005) and Measnet (2009). The relevant obstacles affecting the MM3 are the Nordex N80 wind turbines in the North direction at a distance of 283 and 201 m at the direction angles of 30 and 315° respectively with the North. The cup, sonic and Lidar provide measurements at 3 common heights i.e. 52, 80 and 108 m heights. The Lidar provides measurements at additional heights which are not considered in this study.

The MM3 is a lattice tower mast with guy wires for support. The mast is constructed with tubular elements making

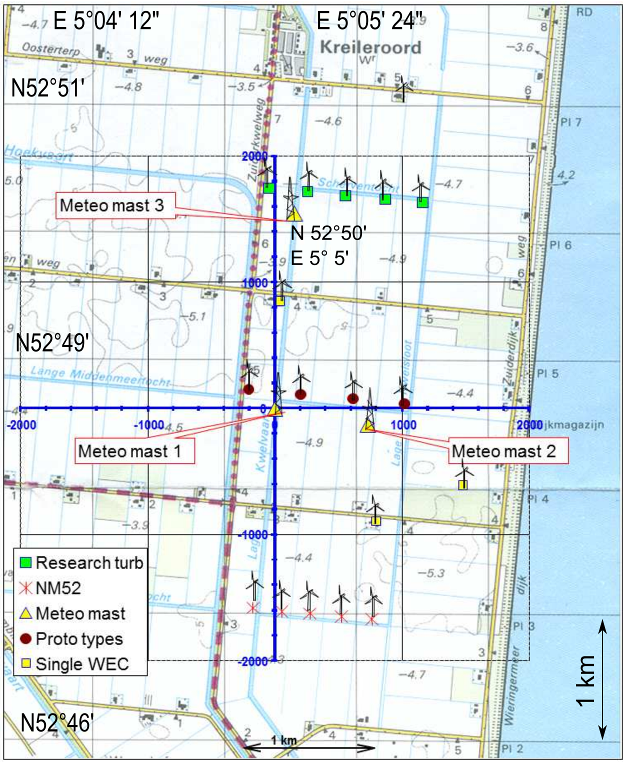

Figure 1. EWTW test site with Nordex N80 prototype wind turbine.

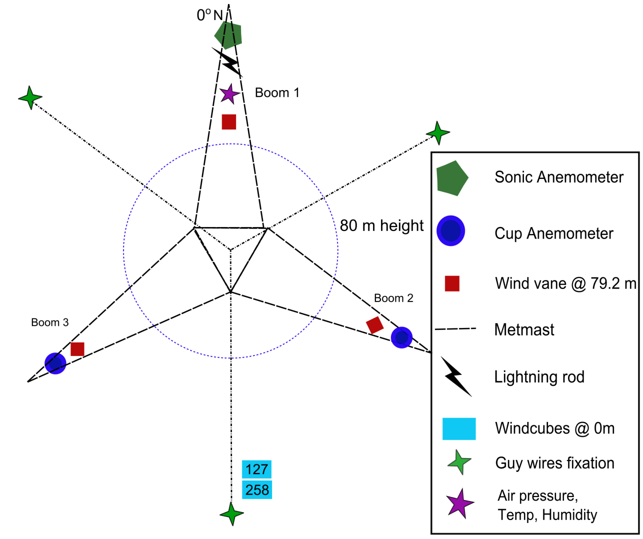

Figure 2. Meteorological mast 3 top view at 80 m height.

Table 1. Filters used for data filtering.

Filter Description	Criteria	Effect
Stuck sensor filter	$D_s = 0.001°$ $D_\delta = 0.1°$	Minor
Despiking	1st and 2nd moments	Minor
Metmast shadow effects	160–200°	Major
CNR filter	−22 dB	Minor
Wake effects	Generally 20–90° 300–340°	Major
Offset filter	dependent	Major
Wind speed	$< 1\,\mathrm{m\,s^{-1}}$	Major
Wind direction	0–360°	Minor
Availability	> 75 %	Minor
Rain filter	Humidity > 75 %	Minor

an equilateral triangle cross section of length 1.6 m. The guy wires are fixed at 50 and 90 m levels and are connected to the concrete bases 60 m away from the tower base at 60, 180 and 300° with respect to North as seen in Fig. 2. There are three boom locations on MM3, namely 0, 120 and 240° at two different height levels at 50.4 and 78.4 m. The two wind vanes, two cup anemometers and one sonic anemometer are installed on the booms at 52 and 80 m height levels. One sonic anemometer is installed at 108 m height. Two vertical scanning pulse WindCube Lidars from Leopshere AG are installed at 180° from the North.

2.2 Data description

The data from the MM3 at EWTW used for this study is collected for the period 1 July 2013 to 26 January 2014, approximately 30 weeks (Bergman et al., 2014). The data includes 10 min averages amounting to roughly 30240 data points measured with the existing measurement standards (Measnet, 2009). The wind direction measurements from two wind vanes is combined into one wind direction measurement considering wake free sectors. Similar method is applied to the wind speed measurements from the cup anemometers for reducing the metmast shadowing effects (Bergman et al., 2014). The sonic anemometer at 52 m is available until mid October.

Lang and Mckeogh (2011) and Westerhellweg et al. (2010) discuss about filtering of the Lidar which is however restricted to the continuous wave Lidar and parameters like low wind speeds, CNR values, wind directions and wake sectors. The extended data filtering is performed according to the procedure as shown in Table 1. The metmast shadow effects are valid for sonic anemometers as the cup anemometers are already averaged to minimize those effects. Further considerations to limit the Carrier to Noise ratio, CNR between −17 and 0 dB are being made since, only wind speeds lower than $10\,\mathrm{m\,s^{-1}}$ were found between 0 and 20 dB. While, the scatter of wind speed between −22 and −17 dB was high ($R^2 = 0.65$). D_s is the standard deviation lower limit while the D_δ is the minimum allowable difference between two consecutive measurements as shown in Table 1.

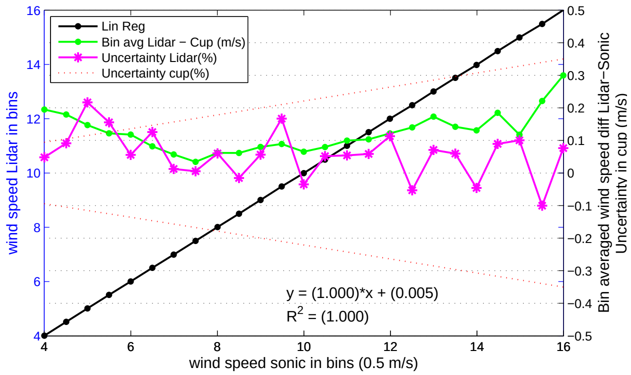

Figure 3. Verification test for wind speed deviation between Lidar and cup anemometer at 80 m height.Verification test comprising of the binwise deviations of the wind speed difference between cup and Lidar, uncertainty of cup and statistical uncertainty of the test.

Table 2. Verification tests and Sensitivity tests for MM3 for Lidar and sonic anemometer when compared against the reference cup anemometer. The accuracy classes are approximated according to the CD-IEC 61400-12-1 Ed.2 description in Albers et al. (2012). The variables counted in the uncertainty are crossed for reference.

Verification Test					
Variable		Lidar		Sonic	
heights		52 m	80 m	52 m	80 m
Wind speed (%)		2.33	2.42	2.6	2.26
Wind direction		3.74	4	2.85	3.5
Wind shear (%)		5.97		4.45	
Sensitivity test					
Variable	Acc. Class	Lidar		Sonic	
heights		52 m	80 m	52 m	80 m
wind veer (%)	X	9.1	4.3	13.02	2.8
wind shear (%)	X	1.79		2.18	
Precipitation (%)	X	0.12	0.21	0.51	0.45
CNR (%)	X	1.63	0.54	n/a	n/a
Availability (%)	X	0.97	1.17	n/a	n/a
Temperature (%)		1.76	1.6	9.2	8
wind speed (%)		0.13	1.78	2.99	3.38
Air pressure (%)		0.1	1.1	0.2	5.25
Lapse rate (%)	X	2.29	2.09	1.46	1.51
TI (%)	X	0.11	1.1	6.86	11.1
Acc. Classes (%)		6.89	3.8	10.57	8.31
Total Uncertainty					
Verification (%)		2.23	2.42	2.6	2.26
Sensitivity (%)		3	2	4	3.5
Mounting (%)		1	1	1	1
Total (%)		3.86	3.3	4.87	4.28

3 Uncertainty calculations

Lindelöw-marsden (2009) has suggested various factors affecting the wind resource assessment using Lidar and quantified the uncertainties theoretically and experimentally. Albers et al. (2009) performed intensive testing of the Lidar and compared the Lidar measurements with metmast measurements which suggested a correlation of close to one in flat terrain. For his study, a test campaign according to the new draft of power curve measurement standard CD IEC 61400-12-1 Ed.2 was performed with WindCube Lidar. Albers et al. (2012) used Verification tests, Sensitivity tests and other tests for Lidar measurement quality assurance and to quantify various atmospheric variables. A study replicating the method is applied at the EWTW test site and extended to include atmospheric variables such as the lapse rate, precipitation and wind veer providing important characteristics of a site. These variables and the Lidar related variables like the CNR and Lidar availability are not yet included into the draft standard and are therefore recommended for consideration.

The method according to CD IEC 61400-12-1 Ed.2 determines the accuracy classes of the Lidar measurement based on the predetermined atmospheric variables affecting the Lidar measurement. The accuracy classes are derived using the verification tests, see Fig. 3, sensitivity tests, Noise tests and Control test using a small mast for correlations, see Albers et al. (2012). The results of the tests for the EWTW test site for MM3 are shown in Table 2. The verification test results as in Table 2 match the ranges also suggested by Albers et al. (2012). Here, the procedure was extended to include wind shear and wind direction also. The Sensitivity test results are derived by the deviation of wind speed as a function of the variables listed. The accuracy classes are then derived by summing the sensitivity test uncertainties and dividing by $\sqrt{2}$, see Albers et al. (2012) for details. The accuracy classes are found to be in higher ranges than found by Albers. Uncertainty in wind speed are approximated from accuracy classes using Albers's description. The high uncertainty originates mainly from wind shear and wind veer supporting the literature well. The uncertainties in the sensitivity test from CNR, Lidar availability and the lapse rate, see Fig. 4 are of significant proportions to be neglected and shall be included into the CD IEC 61400-12-1 Ed.2.

4 Effects of wakes on Lidar beam averaging

The Windcube probes the atmosphere with 4 beams in the directions North, South, East and West direction. The North beam of the Lidar is calibrated with the magnetic North and the Lidar self calibrates itself regularly to check for errors. When one or more of the beams are in the wake sector, this results into an additional uncertainty into the Lidar measurements. To quantify this uncertainty, different scenarios of beam under wake are analytically calculated and applied as a correction on the measurement data.

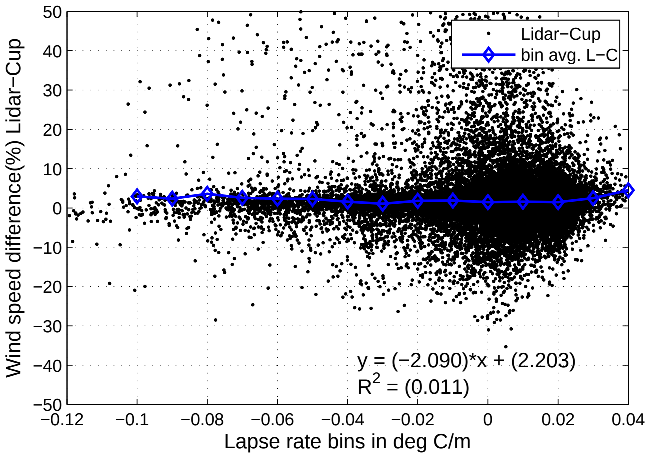

Figure 4. Sensitivity analysis(Slope multiplied with the range) of deviation of wind speed between Lidar and cup anemometer against the Lapse rate.

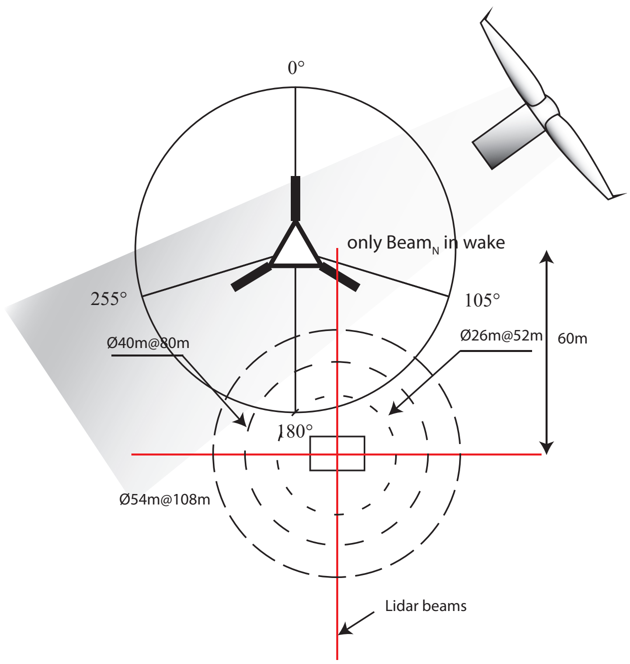

Figure 5. Only the North beam within the wake with 25 % reduction, The 0° represents the North and the Lidar beam N is calibrated with the north direction.

Consider a wake from the nearby turbine N80 which is 283 m away from the met mast which reduces the incident velocity at the mast with 25 %. By solving the system of equations of the Lidar, see Eq. (1), for this reduction in the horizontal wind speed component, u, where u_o is the original u component of the wind speed measured with a sensor without the reduction. In the Fig. 5, the wake affects only the North beam and hence we reduce the measured u component velocity with 25 % in the Eq. (1). This could be seen in the Table 3 where the 25 % is reduced as a fraction in the first case. There are 4 different beams corresponding to four directions as in the Lidar measurement system. The terms $\mathrm{WsL_o}$ and $\mathrm{WsL_{wake}}$ are the incident undisturbed velocity and the wake velocity respectively. The term WsRat Equal, HighU and HighV denote that the u and v values are equal ($u = 10\,\mathrm{m\,s^{-1}}$, $v = 10\,\mathrm{m\,s^{-1}}$), u is higher ($u = 10\,\mathrm{m\,s^{-1}}$, $v = 2\,\mathrm{m\,s^{-1}}$) and v is higher ($u = 2\,\mathrm{m\,s^{-1}}$, $v = 10\,\mathrm{m\,s^{-1}}$) respectively.

Table 3. Lidar beam averaging cases and their effects in percentages depending on beam in wake.

	Beam				WsRat	WsRat	WsRat
No	N	W	S	E	Equal	HighU	HighV
1	0.75	1	1	1	7.38 %	13.80 %	0.60 %
2	0.75	1	0.75	1	17.85 %	31.20 %	1.50 %
3	0.75	0.75	1	1	14.30 %	14.30 %	14.30 %
4	0.75	0.75	0.75	1	24.20 %	32.65 %	15.08 %
5	0.75	0.75	0.75	0.75	33.33 %	33.33 %	33.33 %
6	1	1	1	0.75	7.38 %	0.60 %	13.80 %
7	1	0.75	1	0.75	17.85 %	1.50 %	32.20 %
8	1	1	0.75	0.75	14.30 %	14.30 %	14.30 %
9	1	0.75	0.75	0.75	24.20 %	15.08 %	32.65 %

$$u = \frac{2u_o}{\mathrm{Beam_N} + \mathrm{Beam_S}}; \qquad v = \frac{2v_o}{\mathrm{Beam_E} + \mathrm{Beam_W}} \tag{1}$$

$$\mathrm{WsL_{wake}} = \sqrt{u^2 + v^2}; \qquad \mathrm{WsL_o} = \sqrt{u_o{}^2 + v_o{}^2} \tag{2}$$

$$\mathrm{WsRat} = \frac{\mathrm{WsL_{wake}}}{\mathrm{WsL_o}} \tag{3}$$

A simplified LBA correction of 25 % was applied to the Lidar measurements at 108 m height. For obvious reasons, the mean wind speed ratio in the wake region was reduced by 15 %. The velocity surplus of the Lidar is the same as velocity deficit for the cup and sonic anemometers. It is of the author's opinion that the wake sector is intensified and a peak is obtained as seen in Fig. 6 because the number of beams in wake increases from one to two and two to three and reduces again till the Lidar is outside the wind turbine wake. Even after correction, the peaks in the Fig. 6 remain and this is the effect of wind turbine wakes on the metmast sensors. An advanced application of this method would be to use a wake deficit fraction from Jensen's wake model (Jensen, 1983) on each beam and to perform the beam averaging correction based on $1\,\mathrm{m\,s^{-1}}$ bins along with the wake model as a combined correction.

5 Conclusions

The filtering of Lidar data could be improved by using the extra three variables for filtering namely, CNR, Lidar availability and Precipitation and Humidity values into consideration.

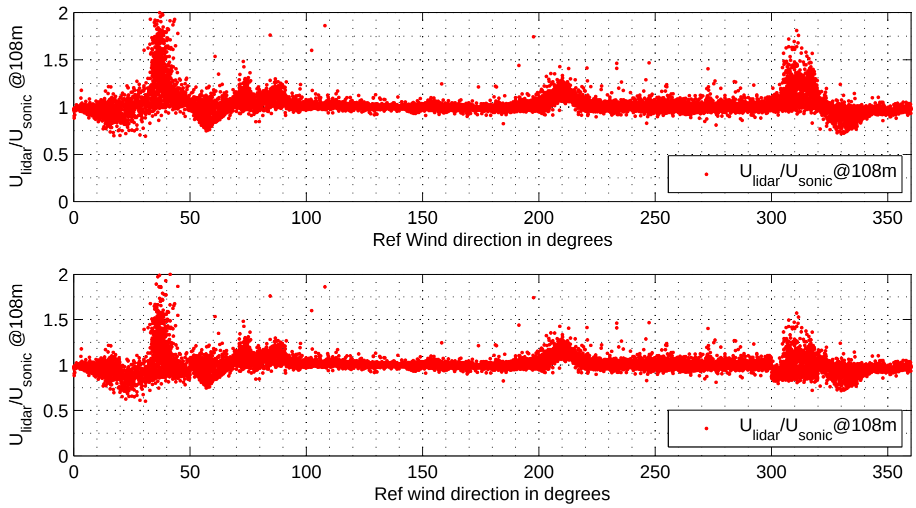

Figure 6. Wind speed ratio representing wakes without(top) and with LBA correction(bottom), correction in the range 20–50 and 300–320°.

The uncertainty due to the atmospheric lapse rate, Lidar availability and CNR, and precipitation account for an independent uncertainty which cannot be neglected and shall be introduced into the CD IEC 61400-12-1 Ed.2 for power curve standard. The uncertainty in wind speed measurement of Lidar was around 3–4 % and that of sonic anemometer was between 4–5 %. The uncertainty calculated as a result is on the higher side when compared to the ones in the literature. This was expected as more uncertainties have been included into the uncertainty analysis.

The simple Lidar beam averaging correction method employed in this study resulted into 15 % improvement in the mean wind speed ratio within the wake sectors. A combination of bin-wise correction along with a wake model will provide better quantification of flow modelling uncertainty in Lidars.

Acknowledgements. This work was carried out in the framework of the LAWINE project with the subsidy of the Dutch funding scheme TKI "Wind op Zee". The following project partners are acknowledged for their contributions: ECN, the Netherlands, XEMC Darwind BV, the Netherlands and Avent Lidar Technology, France.

Edited by: S.-E. Gryning
Reviewed by: two anonymous referees

References

Albers, A., Janssen, A. W., and Mander, J.: German Test Station for Remote Wind Sensing Devices, Tech. Rep. 0, 2009.

Albers, A., Franke, K., Wagner, R., Courtney, M., and Boquet, M.: Ground-based remote sensor uncertainty – a case study for a wind lidar A., Proceeding of EWEA2012, Copenhagen, 2012.

Bergman, G., Wagenaar, J. W., and Boorsma, K.: LAWINE instrumentation report, ECN-X–14-085, ECN, the Netherlands, 2014.

Boquet, M., Görner, K., and Mönnich, K.: Wind Measurement Strategies to Optimize Lidar Return on Investment, EWEA Conference 2011 Proceedings, 2011.

IEC: IEC 61400-12-1 Ed.1: Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, Tech. rep., 2005.

Jensen, N.: A note on wind generator interaction, 16 pp. (Risø-M, No. 2411), ISBN: 87-550-0971-9, 1983.

Lang, S. and Mckeogh, E.: LIDAR and SODAR Measurements of Wind Speed and Direction in Upland Terrain for Wind Energy Purposes, Remote Sensing, 3, 1871–1901, 2011.

Lindelöw-marsden, P.: Uncertainties in wind assessment with LIDAR, vol. 1681, Upwind Task D1 report, Wind Energy Division, TEM (Risø-R-1681 EN), 2009.

Measnet: MEASNET Procedure: Evaluation of Site Specific Wind Conditions, Version 1, November 2009, Tech. Rep. November, Measnet Network of Wind Energy Institutes, 2009.

Smith, D. A., Harris, M., Coffey, A. S., Mikkelsen, T., Jørgensen, H. E., Mann, J., and Danielian, R.: Wind lidar evaluation at The danish wind test site in høvsøre, Wind Energy, 9, 87–93, 2006.

Westerhellweg, A., Canadillas, B., Cañadillas, B., Beeken, A., and Neumann, T.: One Year of Lidar Measurements at FINO1-Platform: Comparison and Verification to Met-Mast Data, Proceedings of 10th German Wind Energy Conference DEWEK, 1–5, 2010.