VERIFICATION REPORT

Verification of the remote sensing device:
AQ510 003

at the verification site

Fimmerstad

Västergötland / Sweden

prepared by

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BBB UMWELTTECHNIK
ERNEUERBARE ENERGIEN GMBH

Weiden, 29.10.2014
Report no.: BBB-V1413-1

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Contractor:	BBB Umwelttechnik erneuerbare Energien GmbH
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Date of Order:	22.10.2014
Definition of task:	Verification of the performance of the Sodar AQ510 003 in flat terrain
Verification site:	Ekeskog, Sweden
Method:	1. IEA Wind: Ground-based vertically-profiling remote sensing for wind resource assessment. 1st Edition, 03/2013 [1]
	2. Internal procedure for verifying remote sensing devices
Release:	PDF version

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1 INTRODUCTION

BBB Umwelttechnik GmbH was contracted by AQ System Stockholm AB to verify the performance of the Sodar AQ510 003 (RSD) at the site:

Fimmerstad, Västergötland, Sweden.

The comparative verification measurement has been performed during a 15 days campaign, from 05.09.2014 until 20.09.2014, next to a meteorological mast with a height of 103.8 m above ground level (a. g. l.). The reference meteorological mast (Ref) was manufactured by Cue Dee and commissioned by Triventus Consulting and is equipped with all necessary sensors like cup anemometers and wind vanes.

BBB Umwelttechnik erneuerbare Energien GmbH, Albert-Einstein-Straße 5, 92637 Weiden is accredited and has the competence according to DIN EN ISO/IEC 17025:2005 to define, install, and operate wind measurements as well as to elaborate investigations, reports and certificates in the sector of evaluation of wind resource and energy production of wind turbines according to the following procedures: IEC61400-12-1, FGW TR Part 6 2007-09, BBB-PrV-01_2010-06, BBB-PrV-02_2010-06.

DAkkS Deutsche Akkreditierungsstelle D-PL-11033-01-00

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2 SITE DESCRIPTION

2.1 General

The test site is located between the lakes Viken and the Ymsen in the northeast of the Västergötland province in Sweden. The site for the verification is situated approx. 1.7 km west of Ekeskog, approx. 2.5 km north-east of Bällefors, and approx. 4 km east of Moholm.
The test site position and coordinates of the reference meteorological mast (Ref) and the remote sensing device (RSD) are shown in Fig. 1 and Fig. 2 as well as in Tab. 1.

Fig. 1: Location of the test site and position of the reference meteorological mast (blue) and the tested remote sensing device (red) (Origin aerial photo: Google).

Tab. 1: Position and elevation of met mast and remote sensing device.

	Position (WGS 84, Zone 32)		Elevation
	N	E	in m
Meteorological mast	58.60566°	14.10991°	90 *1
Sodar AQ510 003	58.605417°	14.111583°	90 *1

*1 based on GPS

The test site and its surroundings are characterized by agriculture and forests.

2.2 Description of the test site

The test site is characterized generally by flat terrain with only very small, rather inconspicuous elevations with maximum height variations of less than 3 m within a radius of 300 m and variations of 40 m within a radius of 5 km.

Due to the mainly agricultural use of the area next to the mast, the low forests to the north-west and south-east and the low variation in terrain elevation, one can expect an undisturbed wind flow at least for the upper measurement heights.

The RSD was installed at a distance of approximately 102 m east to the reference mast inside a small trailer.

Fig. 2: Picture of the remote sensing device and the met mast taken from the east [2].

3 INSTRUMENTATION AND DATA AQUISITION

3.1 Reference mast (Ref)

The reference mast was manufactured by Cue Dee and was commissioned by Triventus Consulting in November 2011. It is a guyed lattice tower with a total height of 103.8 m above ground level with high quality MEASNET calibrated cup anemometers and wind vanes. All signals were logged as 10 minute intervals with a Campbell Scientific CR1000 logger.

The description given in this report is based on the information provided by the client as well as on the site visit to the Fimmerstad test site performed by BBB on 17.06.2014.

3.1.1 Description of the met mast

For the acquisition of the wind speed six Thies First Class cup anemometers have been mounted on booms at a distance of 3.7 m to the mast. Further at 3.8 m above the mast structure a Thies Ultrasonic 3D and a Vaisala WAA252 heated cup anemometer were mounted in a side-by-side configuration. The two top anemometers are separated by at least 2.5 m. The wind direction was measured at three heights with Thies First Class wind vanes. The installation of the sensors complies with the requirements of the IEC 61400-12 [3] and [4].

The calibration reports for the sensors were provided by AQ Systems and crosschecked with the programming of the logger. Also a service log book for the met mast was available. Further information about the mast as demanded by [5] can be found in [6] and [7]. Besides the anemometers no further sensors were calibrated. The subsequent tables and figures show the configuration of the sensors at the reference mast.

Tab. 2: Specification of the mounted reference anemometers.

Sensor	Installation height (a. g. l.)	Boom orientation	Sensor type	Serial no.	Slope $m\ s^{-1}\ Hz^{-1}$	Offset $m\ s^{-1}$
A1	103.8 m	317°	Vaisala WAA252	G15403	0.10295	0.2485
A1b *1	103.8 m	137°	Thies Ultrasonic 3D	05120023	0.99426	0.0063
A2	100.9 m	317°	Thies First Class	01142028	0.04603	0.2649
A2b	100.9 m	137°	Thies First Class	01142027	0.04616	0.2383
A3	80.1 m	317°	Thies First Class	011042025	0.04610	0.2541
A3b	80.1 m	137°	Thies First Class	011042026	0.04621	0.2201
A4	60.1 m	317°	Thies First Class	011042023	0.04620	0.2239
A4b	60.1 m	137°	Thies First Class	011042024	0.04615	0.2290

*1 not used for the verification

Tab. 3: Specification of the mounted reference wind vanes and the used temperature sensor.

Sensor	Installation height a. g. l.	Sensor type	Serial no.	Sensor orientation	Boom orientation
D1	97.1 m	Thies 43150	08110633	137°	317°
D2	75.1 m	Thies 43150	08110630	137°	317°
D3	55.1 m	Thies 43150	06110600	137°	317°
Temperature 1	99.9 m	Campbell Scientific 107B		-	-

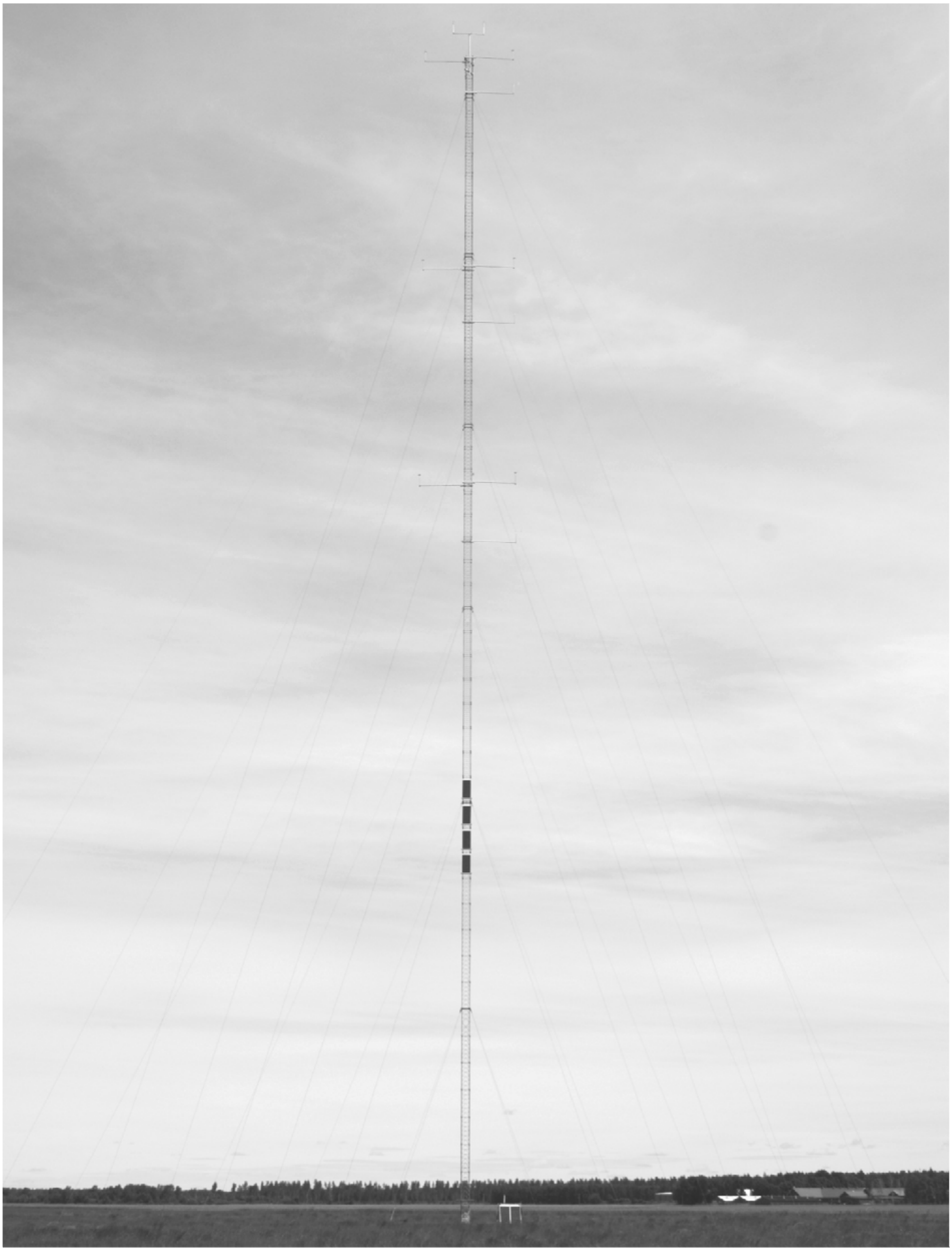


Fig. 3: Mast overview pointing towards NE (photo taken 17.06.2014).

3.2 Remote Sensing Device (RSD)

The Sodar system verified here is the AQ510 003. It was placed in a distance of approximately 102 m east to the reference mast in order to avoid any fixed echo contamination of the signal reception caused by the proximate fixed mast structure (see Fig. 2). The verification measurement lasted for 15 days starting with the 05.09.2014 until 20.09.2014.

Fig. 4: Picture of the trailer containing the RSD next to the reference met mast [2].

3.2.1 Description of the RSD installation

The RSD was configured to measure at 33 different heights in 5 m steps between 40 m and 200 m above ground level. Like the met mast the RSD has been configured to log all measured values at 10–minute intervals. The time synchronisation of this device occurred against a GPS signal every 10 minutes.

Because of the installation of the RSD inside a trailer the real measurement heights above ground are 0.7 m above the configured heights, as shown in the next table.

Tab. 4: RSD configuration and resulting measurement heights.

Configured height in m	Measurement height in m a. g. l.	Configured height in m	Measurement height in m a. g. l.
200	200.7	...	...
195	195.7	60	60.7
190	190.7	55	55.7
185	185.7	50	50.7
180	180.7	45	45.7
...	...	40	40.7

The installation and dismantling procedure of the RSD has been documented by AQ System [2]. No maintenance or other modifications have been done during the verification period. The RSD has been leveled by a digital inclination sensor in order to be horizontal. Pitch and roll were equal or below ±0.5° at installation and dismantling of the RSD.

Tab. 5: Inclination and direction offset at installation and dismantling of the RSD.

	Date	North	East	Pitch	Roll	Azimuth to true north
		Geogr, WGS 84				
Installation	05.09.2014	58.605417°	14.111583°	≤ ±0.5°	≤ ±0.5°	38°
Dismantling	20.09.2014	58.605417°	14.111583°	≤ ±0.5°	≤ ±0.5°	38°

Further information about the installation of the RSD can be found in [2].

4 VERIFICATION PROCEDURE

To verify the performance of the RSD the 10 min average wind data of the RSD has been compared to the reference measurement. Both data sets are filtered before evaluation according to several criteria. Based on this data deviations and different regression approaches have been calculated to compare the remote sensing device (RSD) with the reference mast (Ref).

Data analysis

The analysis of the data was performed with Windographer and R [8]. All analyses comply with the recommendations of the IEA guideline [1] about the verification of ground-based remote sensing devices.

At the met mast at all heights, except for the top, two collocated cup anemometers were installed. Therefore to reduce the effect of tower shading the used cup anemometer was depended on the wind direction. For wind directions between 47° and 227° data from the cup anemometers on the south-eastern boom were taken and vice versa. For the top measurement just the Vaisala sensor (A1) was used.

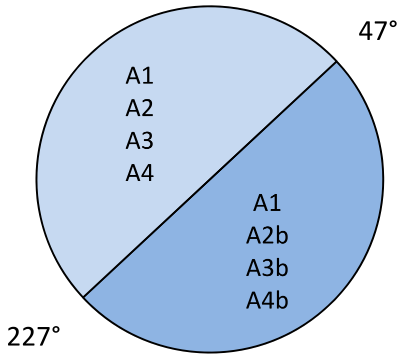


Fig. 5: Wind direction and chosen cup anemometer.

4.1 System availability

The system availability of the remote sensing device is defined as the quotient of available 10-minute data sets to the maximum possible number of 10-minute data sets within the verification campaign. No data filtering regarding the data quality has been performed up to this point.

Tab. 6: Summary of the RSD system availability.

		Measurement height (in m a. g. l.)			
	Unit	60.7	80.7	100.7	105.7
Max. possible data sets	counts	2175	2175	2175	2175
Data sets excl. NAN (≙ Not a number)	counts	2122	2104	2073	2048
System availability	%	97.6	96.7	95.3	94.2

4.2 Data filtering

After a manual/visual data check several steps of data filtering were performed on the measurement data to ensure that representative/valid data is used and to enhance the repeatability of the verification process.

Data Quality

To ensure a good data quality of the RSD measurement an internal RSD data flag for filtering has been used.

- Individual for each height the measurement data has been filtered for data quality values lower than 21. Only values where the quality signal at the corresponding heights are equal or higher than this value have been considered.

The following figures show the effect of the quality value threshold on the relative difference between the wind speed measured by the reference mast and the wind speed measured by the RSD.

V1

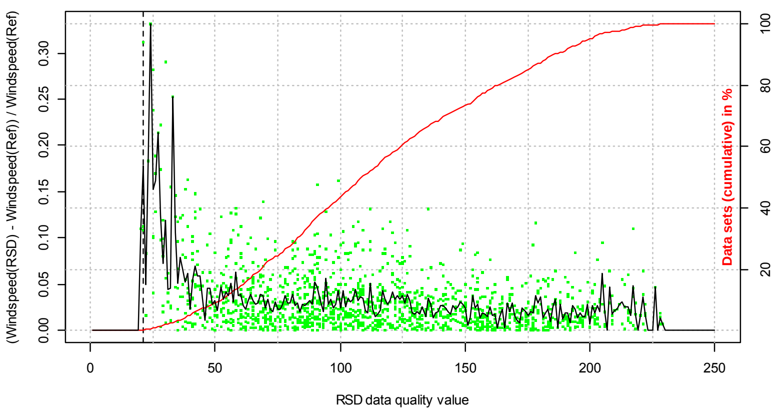
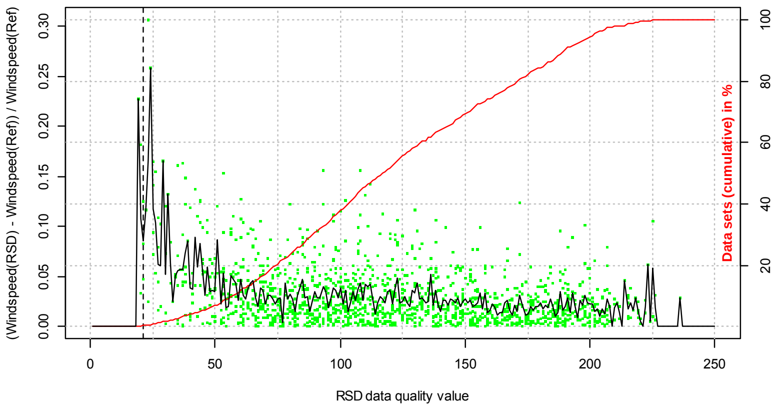
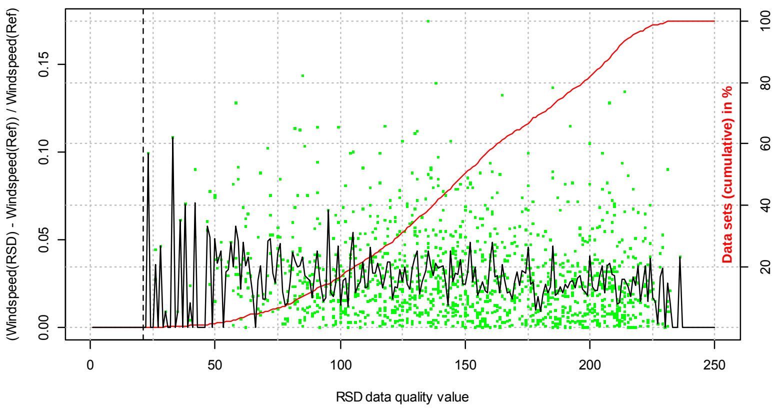


Fig. 6: Relative difference of the measured wind speed between Ref and RSD according to the quality value threshold of the RSD. (V1)

V2



V3



V4

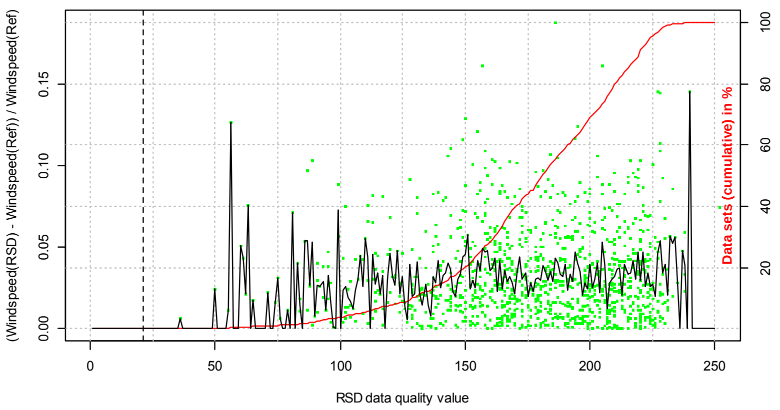


Fig. 7: Relative difference of the measured wind speed between Ref and RSD according to the quality value threshold of the RSD. (V2 - V4)

Icing

The reference mast data has been filtered for icing of the anemometers and wind vanes. First a filtering for obvious icing was done by hand, removing obviously invalid data sets from the met mast. Further the data sets gathered at an air temperature of 2° C or less have been omitted.

Wind speed

Corresponding with the calibration range of standard cup anemometers only wind speeds within the interval 3.75 m/s – 16.25 m/s were considered.

Wind direction

Based on aerial photographs the test site has been analysed for obstacles that could affect the wind measurement as defined in [3].

Tab. 7: Mast effects and obstacles in the surroundings of the test site Fimmerstad and discarded wind direction sectors.

Obstacle/Cause	Start of sector	End of sector	Distance to Ref in m	Measurement height (a. g. l.) 60.1 m	80.1 m	100.9 m	103.8
Forest	47°	170°	680	disturbed	disturbed	undisturbed	undisturbed
North gap	135°	150°	-	omitted	omitted	omitted	omitted
Forest	212°	360°	750	disturbed	disturbed	undisturbed	undisturbed

The measurements at the height of 60.1 m a. g. l. and 80.1 m a. g. l. are influenced by the forests to the northwest and southeast. Applying this filter on the lower measurement heights would result in following data size.

Tab. 8: Available data sets if the disturbed sectors at 60.1 m and 80.1 m a. g. l. would be removed.

Measurement height (a. g. l.)	Number of data sets Total	Wind speed 4 – 8 m/s	Wind speed 8 – 16 m/s
60.1 m	109	103	6
80.1 m	150	144	6

Removing the affected sectors would reduce the available data at the lower measurement heights below the minimum necessary for verification. Therefore these wind directions sectors were not omitted. An analysis of the data shows that the effect of the forest is small, but still this fact needs to be considered in the calculation of the uncertainties for the verification of the lower measurement heights.

Following figure shows the direction filter used within this verification for all measurement heights.

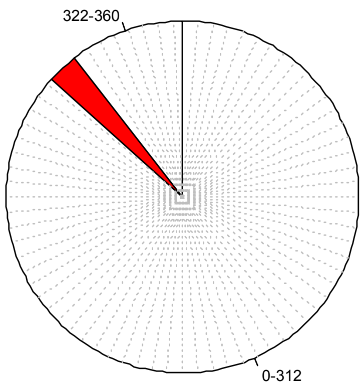


Fig. 8: Visualisation of the excluded (red) and included (white) wind direction sectors for the verification of the RSD.

4.3 Data availability

Applying all filter steps described above, the amount of valid data sets was reduced according to the table below:

Tab. 9: Number of data samples remaining after applying all filter steps for the measurement data from the RSD.

	Unit	105.7 m	100.7 m	80.7 m	60.7 m
Max. possible data sets	counts	2175	2175	2175	2175
Data sets excl. NAN (≙ Not a number)	counts	2048	2073	2104	2122
	%	94.2	95.3	96.7	97.6
Data sets after RSD data-quality filtering	counts	2031	2055	2099	2121
	%	93.4	94.5	96.5	97.5
Data sets after filtering icing	counts	2031	2055	2099	2121
	%	93.4	94.5	96.5	97.5
Data sets after direction filtering	counts	2026	2050	2092	2116
	%	93.1	94.3	96.2	97.3
Data sets after wind speed filtering	**counts**	**1465**	**1456**	**1400**	**1156**
	%	**67.4**	**66.9**	**64.4**	**53.1**

The data sets which are omitted for NAN (not a number) in the first step include data sets that were excluded because of obvious icing at the met mast.
Regarding the data availability, following requirements for the acceptance of the verification need to be fulfilled:

- For each verification height at least 600 valid data sets have to be obtained.
- For each verification height for the wind speed range 4 – 8 m/s at least 150 valid data sets have to be obtained

- For each verification height for the wind speed range 8 – 16 m/s at least 150 valid data sets have to be obtained

Following table shows the results of the data availability analysis:

Tab. 10: Acceptance criteria for the total amount of valid points of RSD datasets.

Acceptance criteria	Requirement	Measurement height (a. g. l.)			
		105.7 m	100.7 m	80.7 m	60.7 m
Valid data sets per height	600	1465	1456	1400	1156
Valid data sets at U_{RSD} with U_{Ref} ≥4 m/s and <8 m/s	150	1408	1406	1374	1145
Valid data sets at U_{RSD} with U_{ref} ≥8 m/s and <16 m/s	150	57	50	26	11

The duration of the 15 days measurement campaign supported by the very good system and data availability of the AQ510 produced enough data to have more than 600 data sets for each height. Also the second data criterion with at least 150 data sets within the 4 m/s to 8 m/s interval could be successfully completed. Unfortunately the measurement period was characterized with low wind speeds. Therefore the third data criterion needing 150 data sets within the 8 m/s to 16 m/s interval could not be successfully completed.

4.4 Data acquisition time synchronisation

The RSD is synchronized against a GPS signal every 10 minutes while the data logger of the met mast is synchronized on a daily basis.
The two data sets showed a good correlation and no time shift could be detected (see figure below).

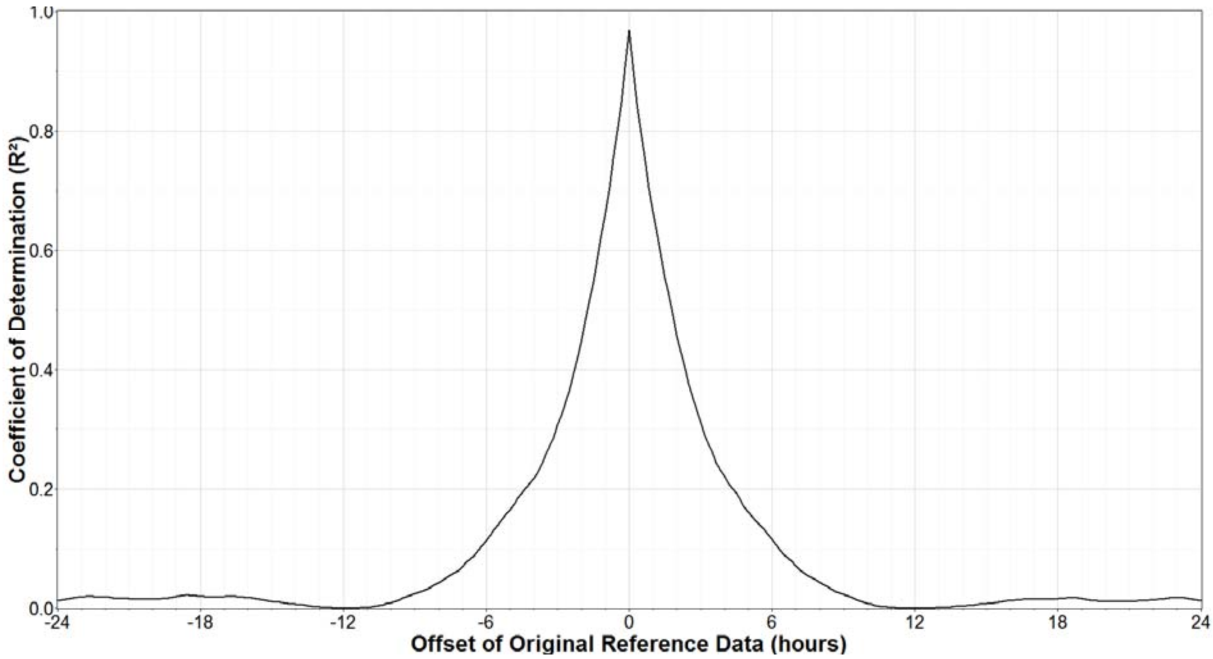


Fig. 9: Results of an autocorrelation function of the Ref (103.8 m) and RSD (105.7 m) measurement.

Therefore we can assume a time synchronic operation of both systems.

The following figure demonstrates the synchronic operation of both measurement systems.

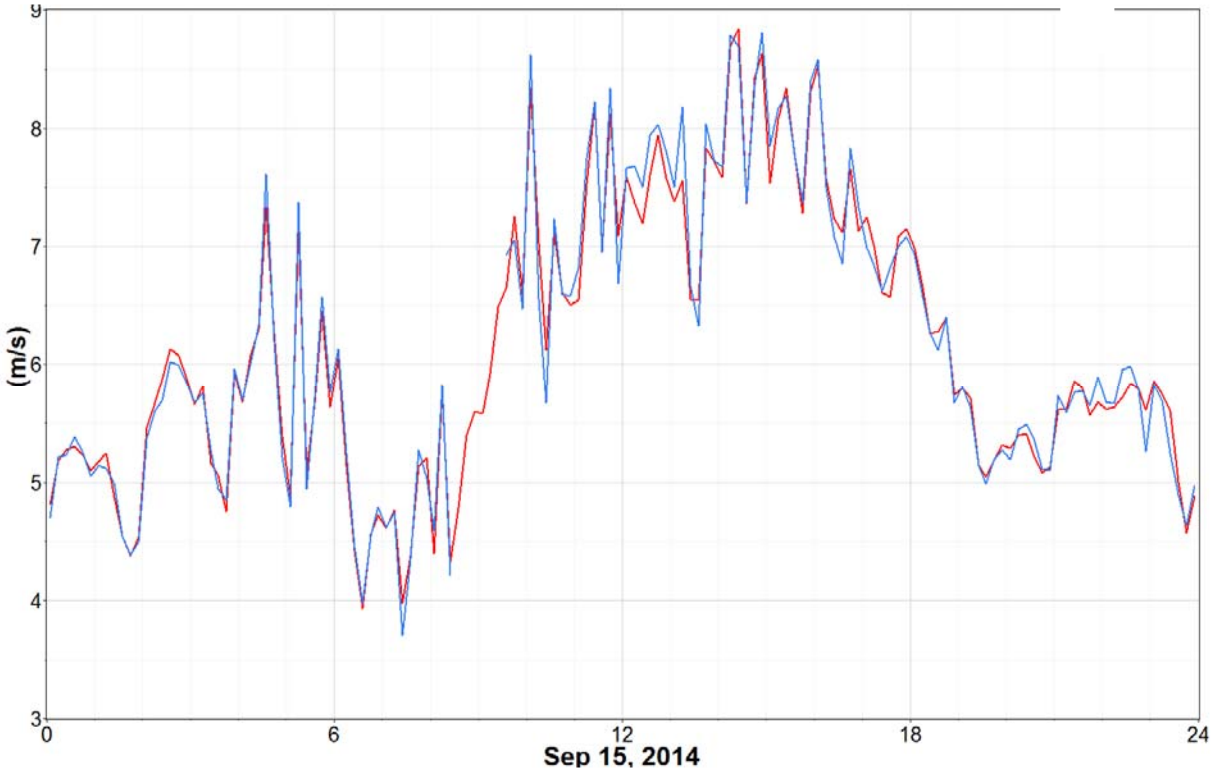


Fig. 10: Time series plot of the measurement data at Ref (103.8 m, red) and RSD (105.7 m, blue).

4.5 Exceptions and deviations from the applied standards

Following exceptions from the applied standards must be mentioned within this report:

- As demanded by [1] the measurement should continue until all bins between 4 m/s and 16 m/s contain at least one hour of data. Because of the low wind situation during the measurement period the number of wind speed measurements with more than 9 m/s did not comply with this requirement.
- For the same reason also the data criterion with at least 150 data sets within the 8 m/s to 16 m/s interval could not be successfully completed.
- At the measurement heights 60.1 m and 80.1 m the direction sectors which might be affected by forests to the northwest and southeast were not excluded from the verification.

BBB categorizes this deviation as minor deviation not further relevant for the verification process.

5 RESULTS

In this chapter the results of this verification campaign are presented. After a description of the wind characteristics during the measurement period the results of the comparison between remote sensing device (RSD) and reference mast (Ref) are given. Further, the performance of the RSD is verified against several acceptance criteria to confirm the valid operation of the RSD for wind resource assessments.

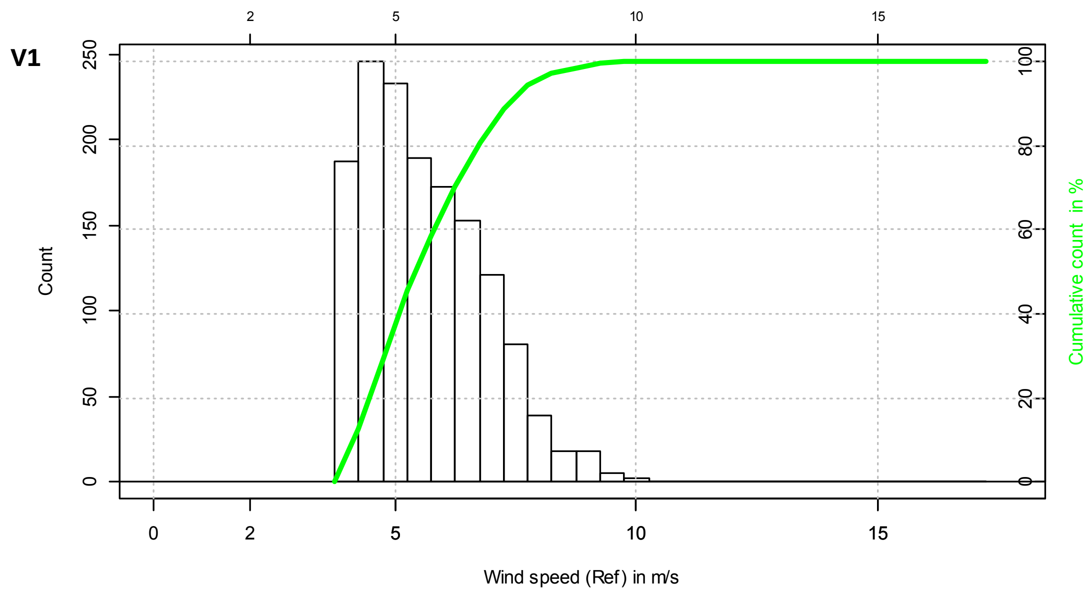
The verification was done for the four cup anemometer heights. Following table defines the congruent measurement heights and sensors compared within this verification procedure:

Tab. 11: Congruent measurement heights and sensors.

Verified	Reference mast (Ref) sensors		Remote Sensing device (RSD)
Height	Wind speed	Wind direction	Measurement height
V1	A1 (103.8 m)	D1 (97.1 m)	105.7 m
V2	A2 & A2b (100.9 m)	D1 (97.1 m)	100.7 m
V3	A3 & A3b (80.1 m)	D2 (75.1 m)	75.7 m
V4	A4 & A4b (60.1 m)	D3 (55.1 m)	55.7 m

5.1 Wind speed distribution

The following figures show the distribution of the filtered reference wind speed data for all compared heights.



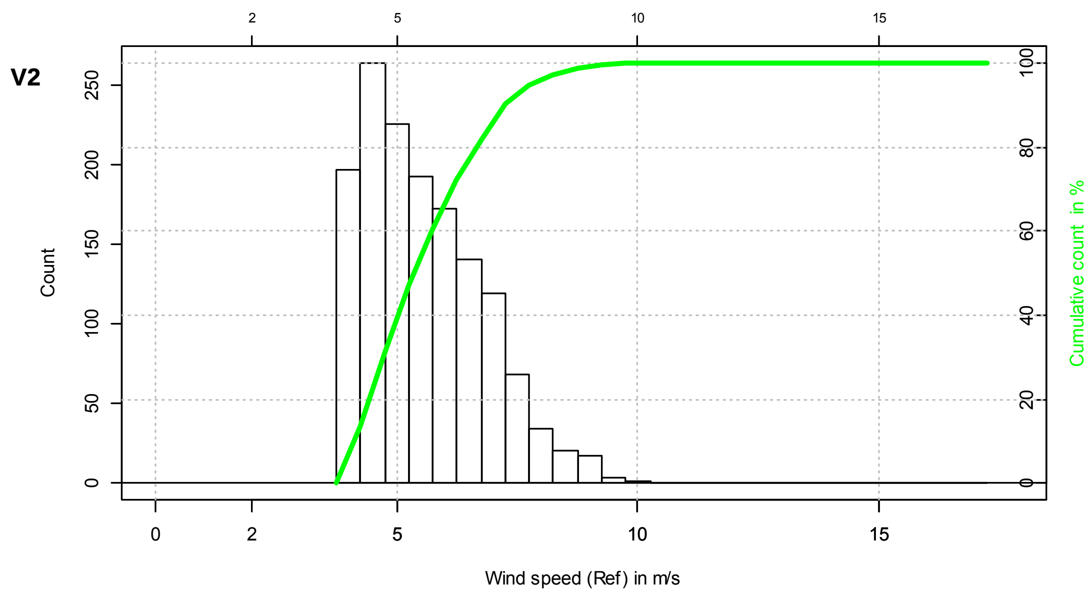
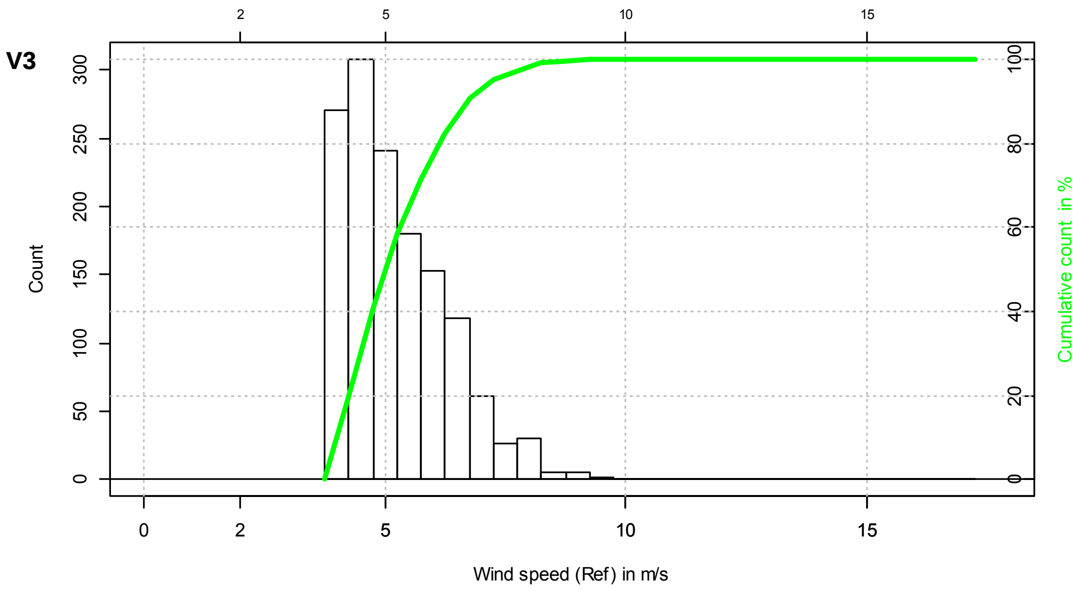


Fig. 11: Frequency of wind speed bins in m/s and the cumulative distribution function (green line) for the reference data. (V1, V2)



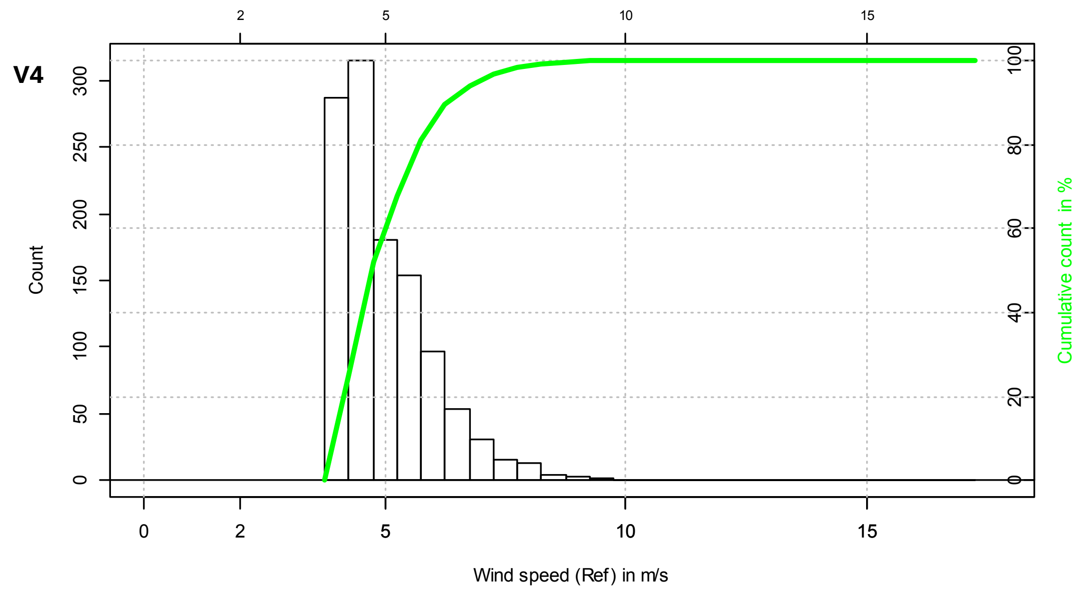


Fig. 12: Frequency of wind speed bins in m/s and the cumulative distribution function (green line) for the reference data. (V3, V4)

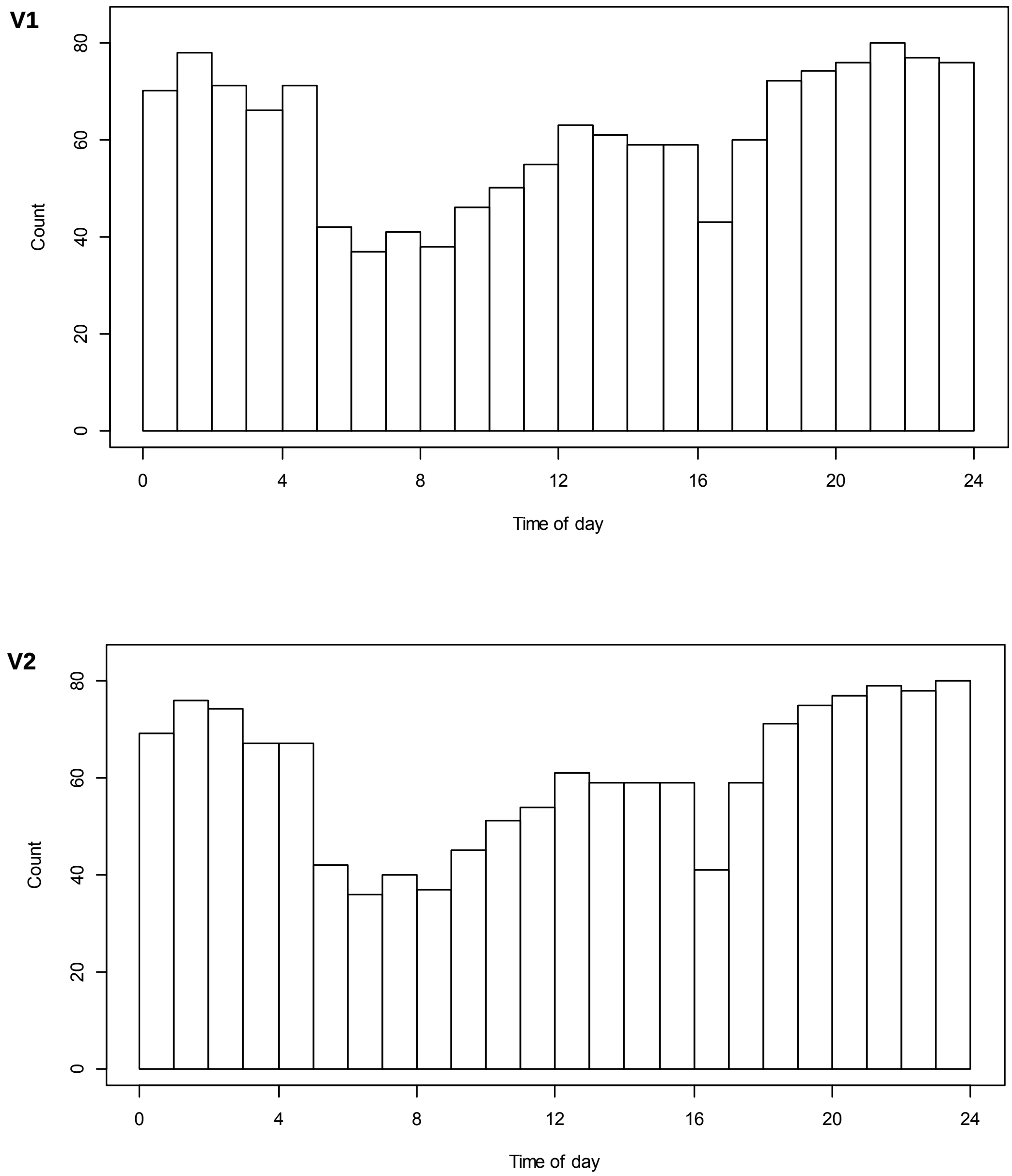
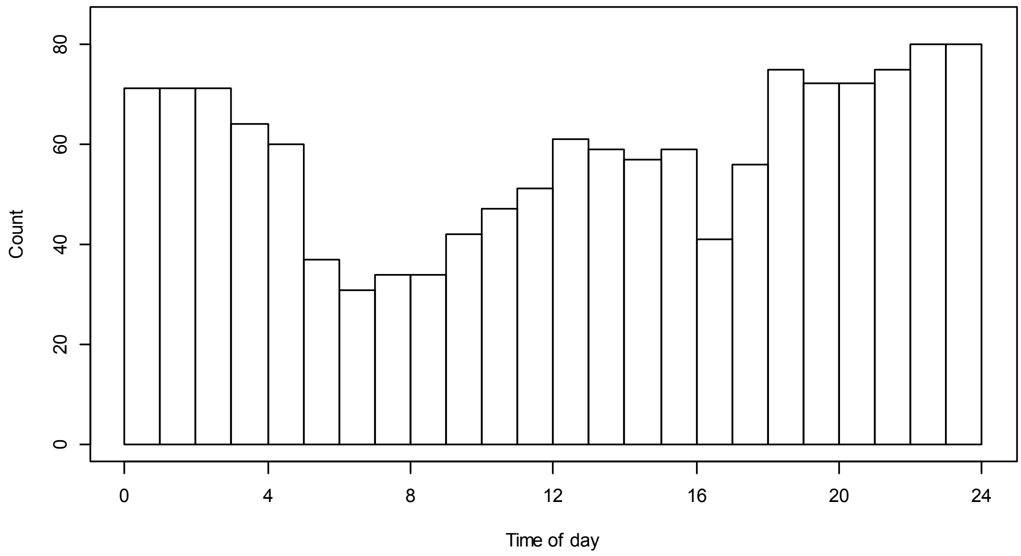


Fig. 13: Diurnal distribution of 10-minute data sets of the reference mast. (V1, V2)

V3



V4

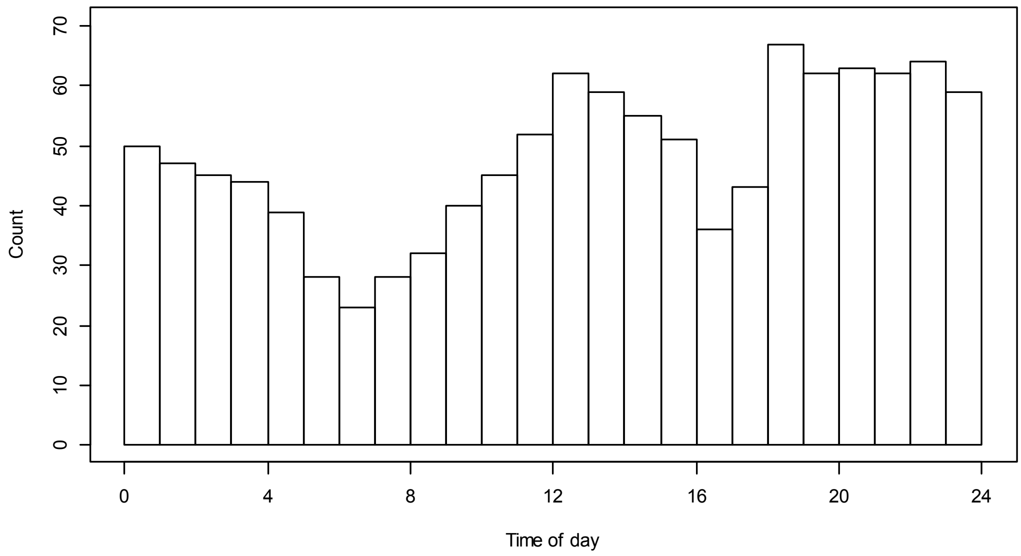
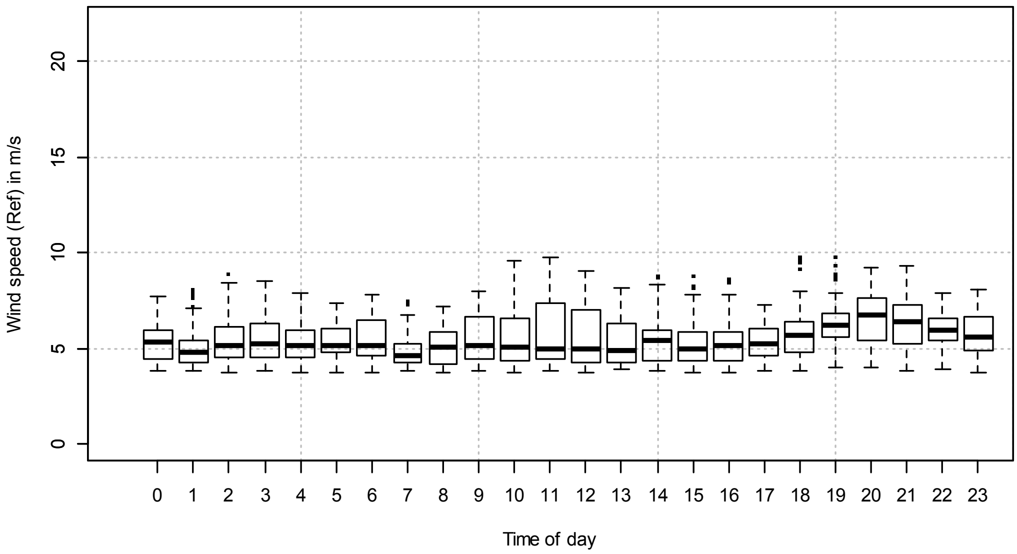


Fig. 14: Diurnal distribution of 10-minute data sets of the reference mast. (V3, V4)

V1



V2

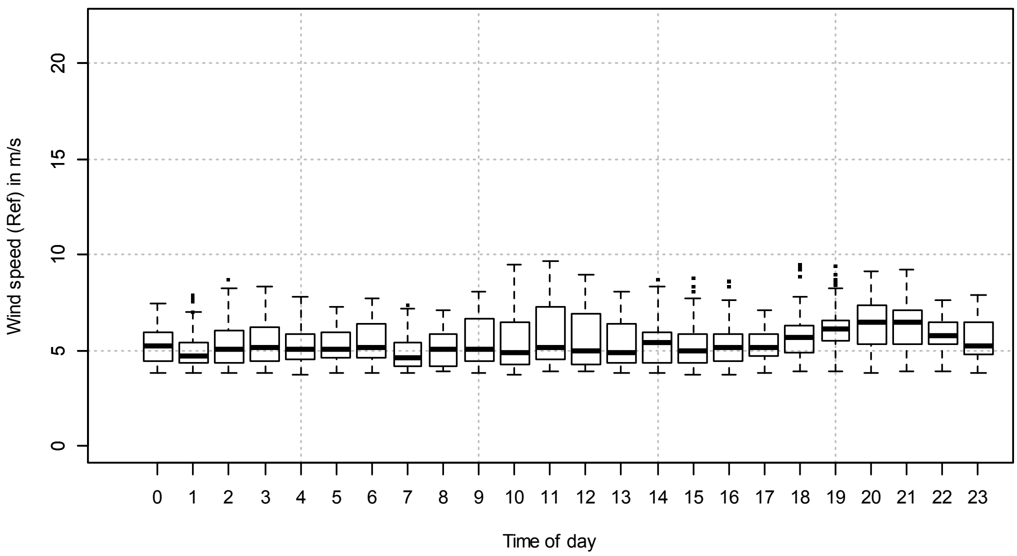
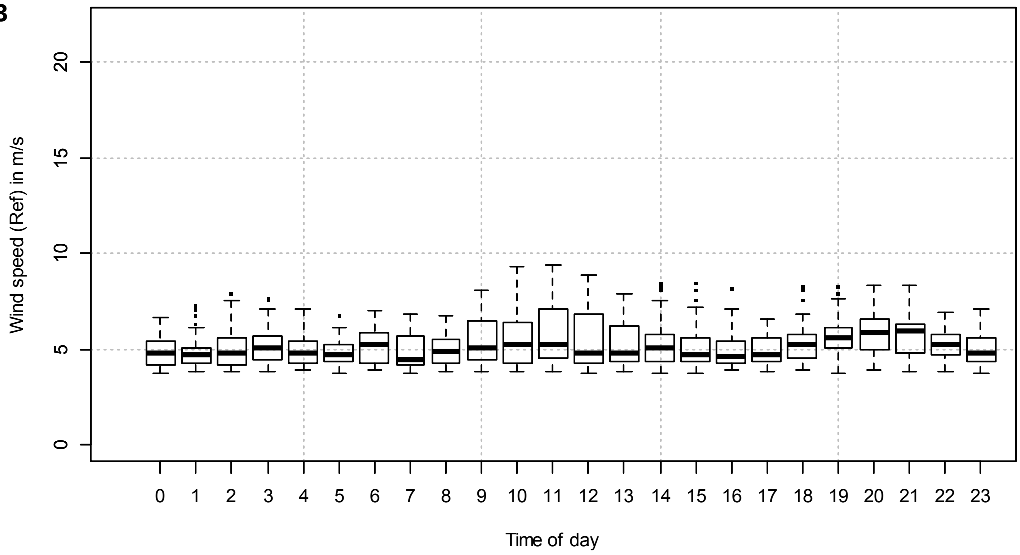


Fig. 15: Diurnal cycle of the wind speed distribution of the reference mast. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. (V1, V2)

V3



V4

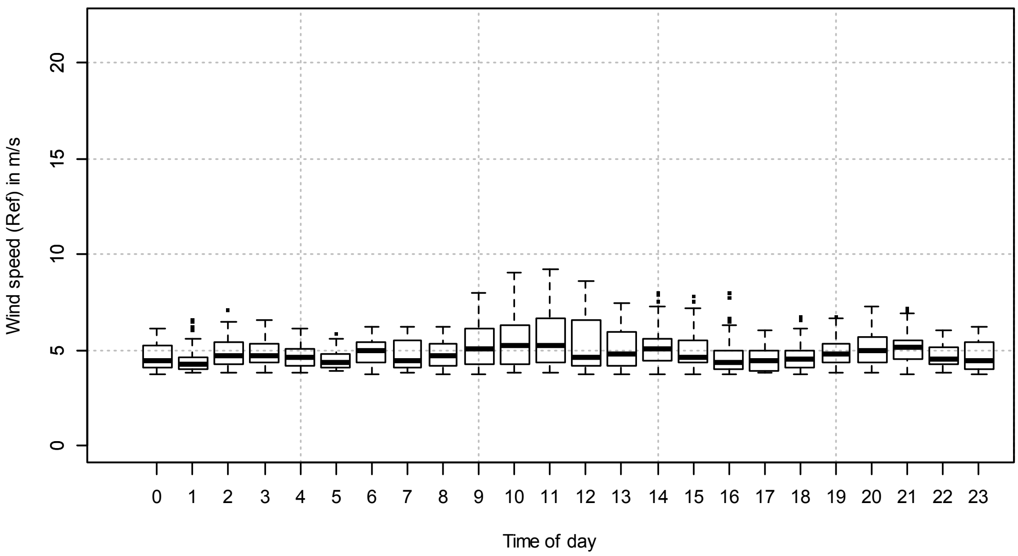
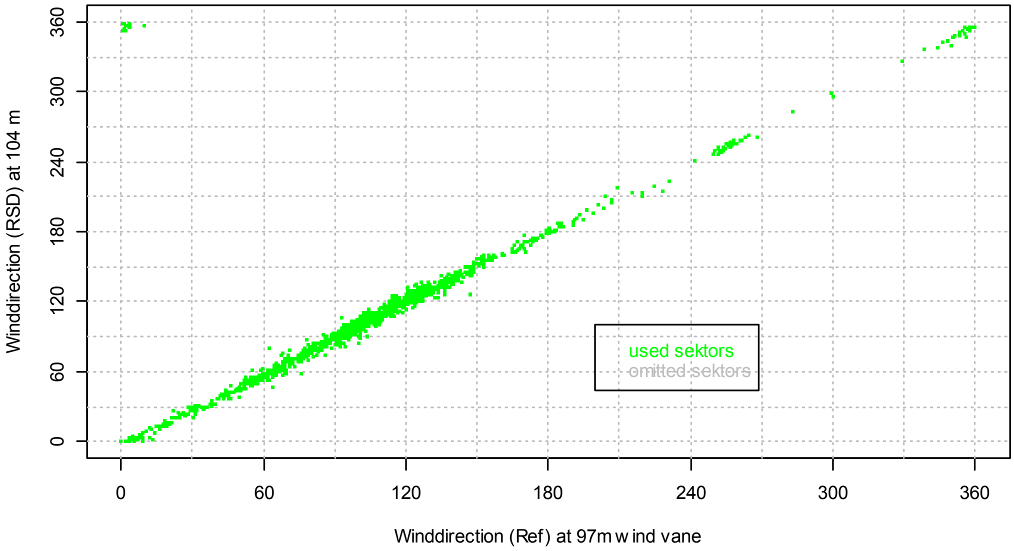


Fig. 16: Diurnal cycle of the wind speed distribution of the reference mast. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. (V3, V4)

5.2 Wind direction at RSD and reference mast

The following figures show the distribution of the filtered reference wind direction data for the compared heights.

V1



V2

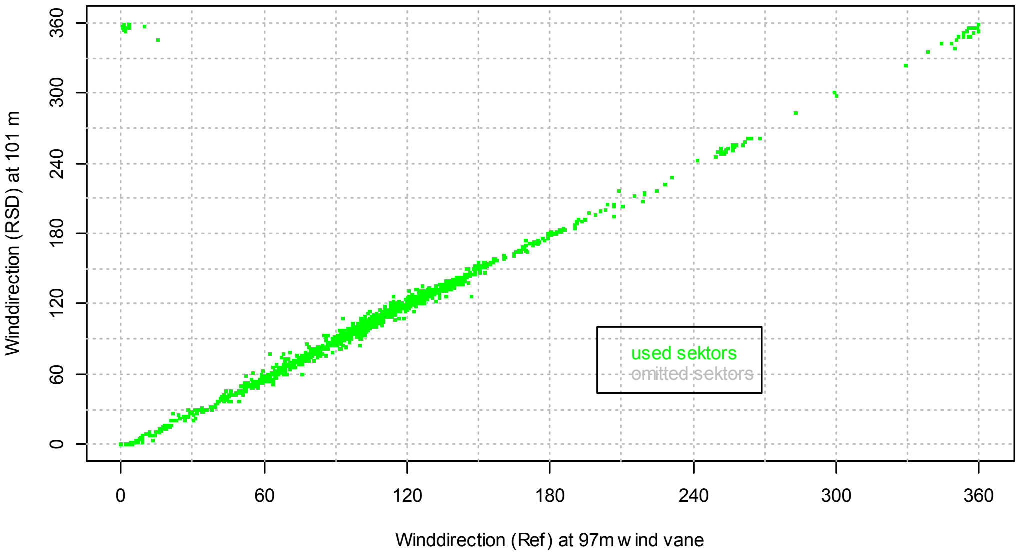
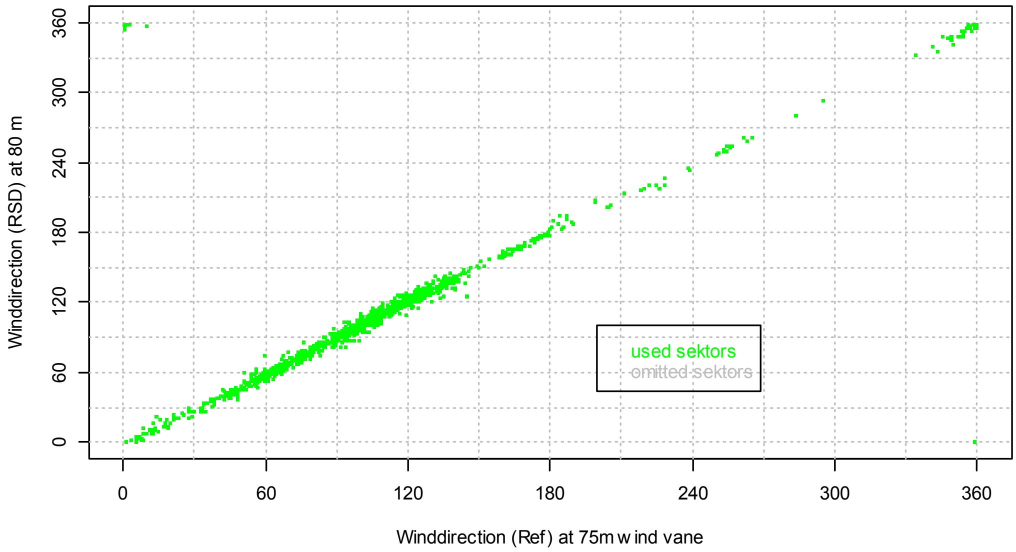


Fig. 17: Wind direction of the RSD (ordinate) versus wind direction at the wind vanes of the reference mast (abscissa). (V1, V2)

V3



V4

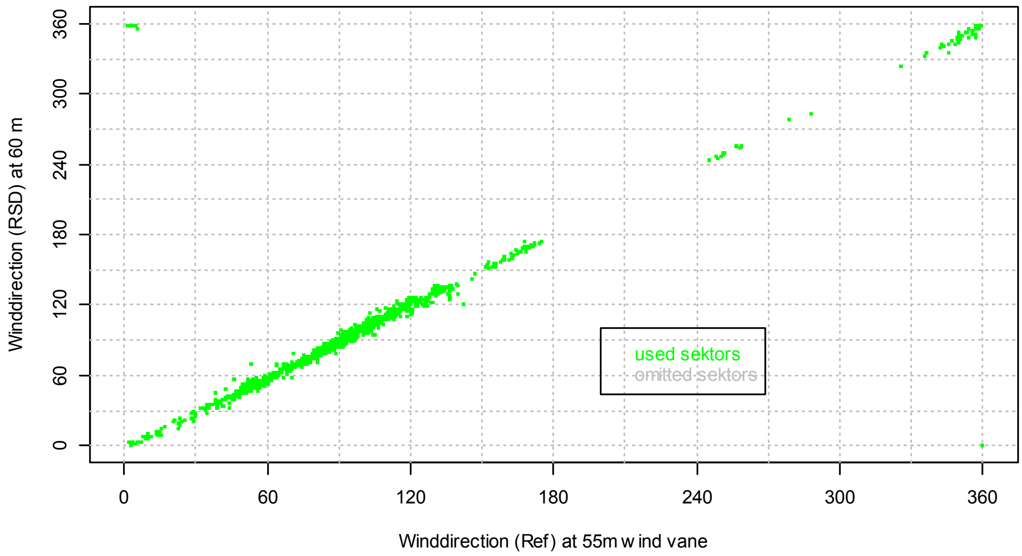
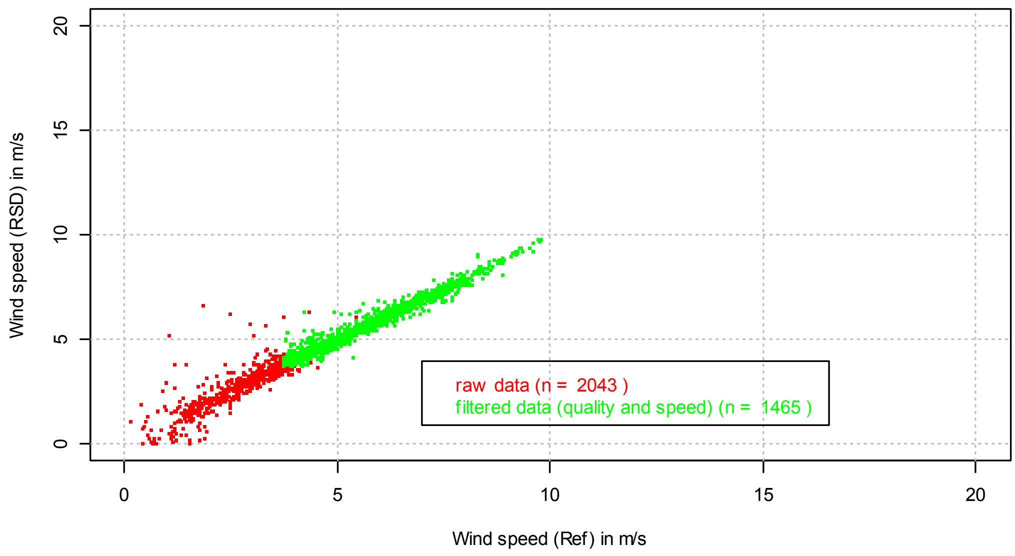


Fig. 18: Wind direction of the RSD (ordinate) versus wind direction at the wind vanes of the reference mast (abscissa). (V3, V4)

5.3 Ten minute mean wind speed of the data

5.3.1 Ten minute mean wind speed of the data at 103.8 m

The results of the analysis comparing the reference data at anemometer V1 and the RSD data of the 105.7 m height measurement are shown in the following figures.



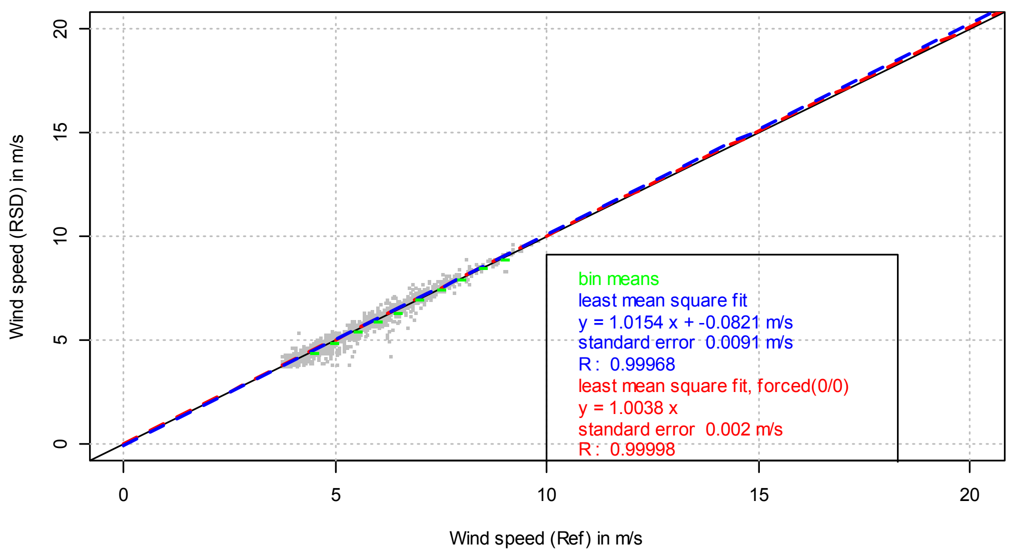
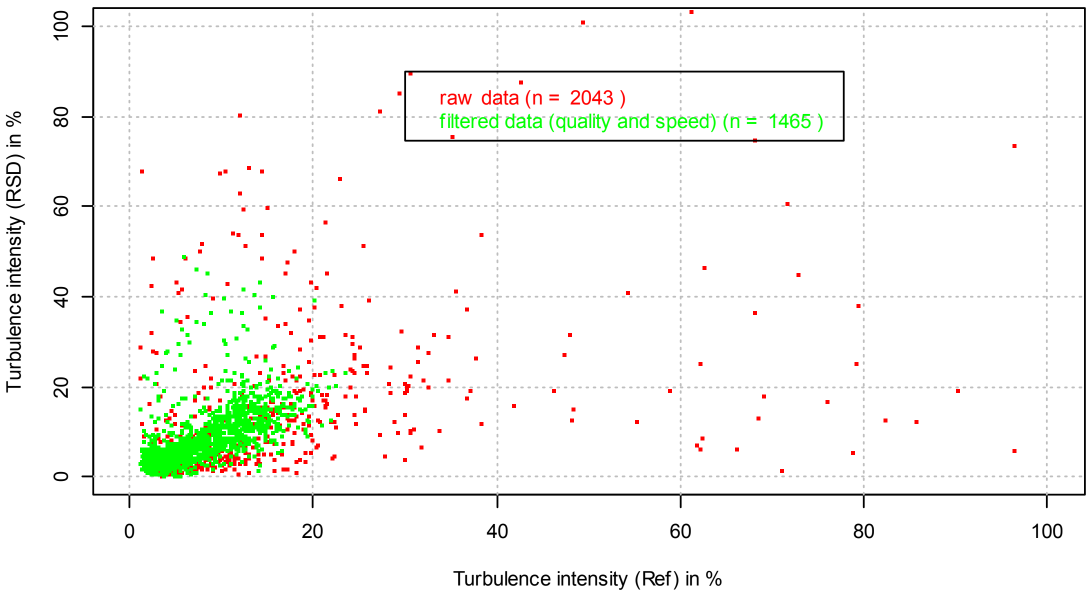


Fig. 19: Wind speed of the RSD (ordinate) versus wind speed reference mast (abscissa). (upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



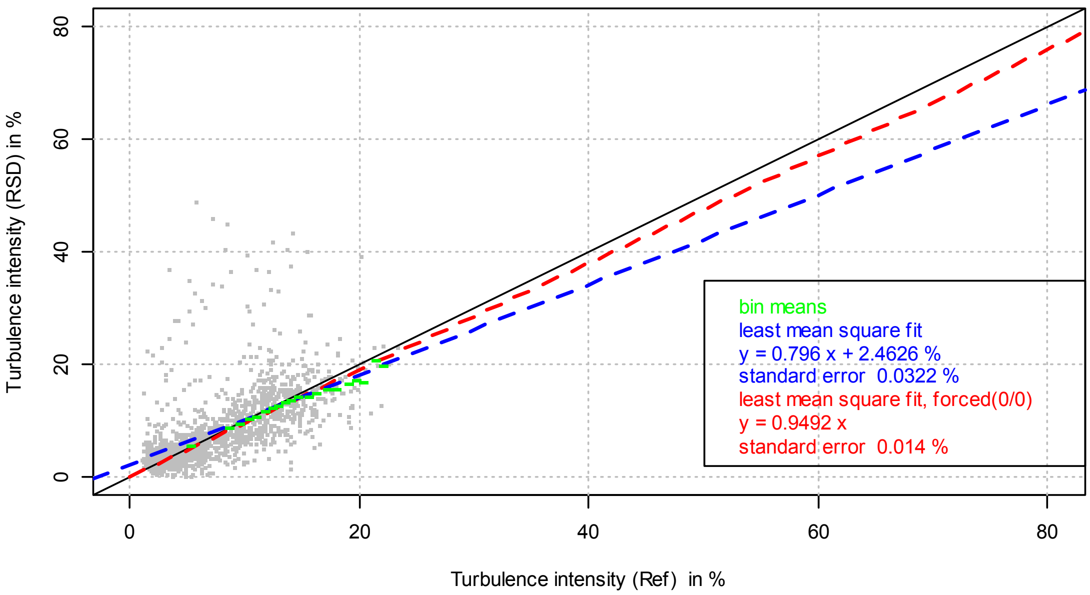


Fig. 20: Turbulence intensity of the RSD (ordinate) versus turbulence intensity reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.

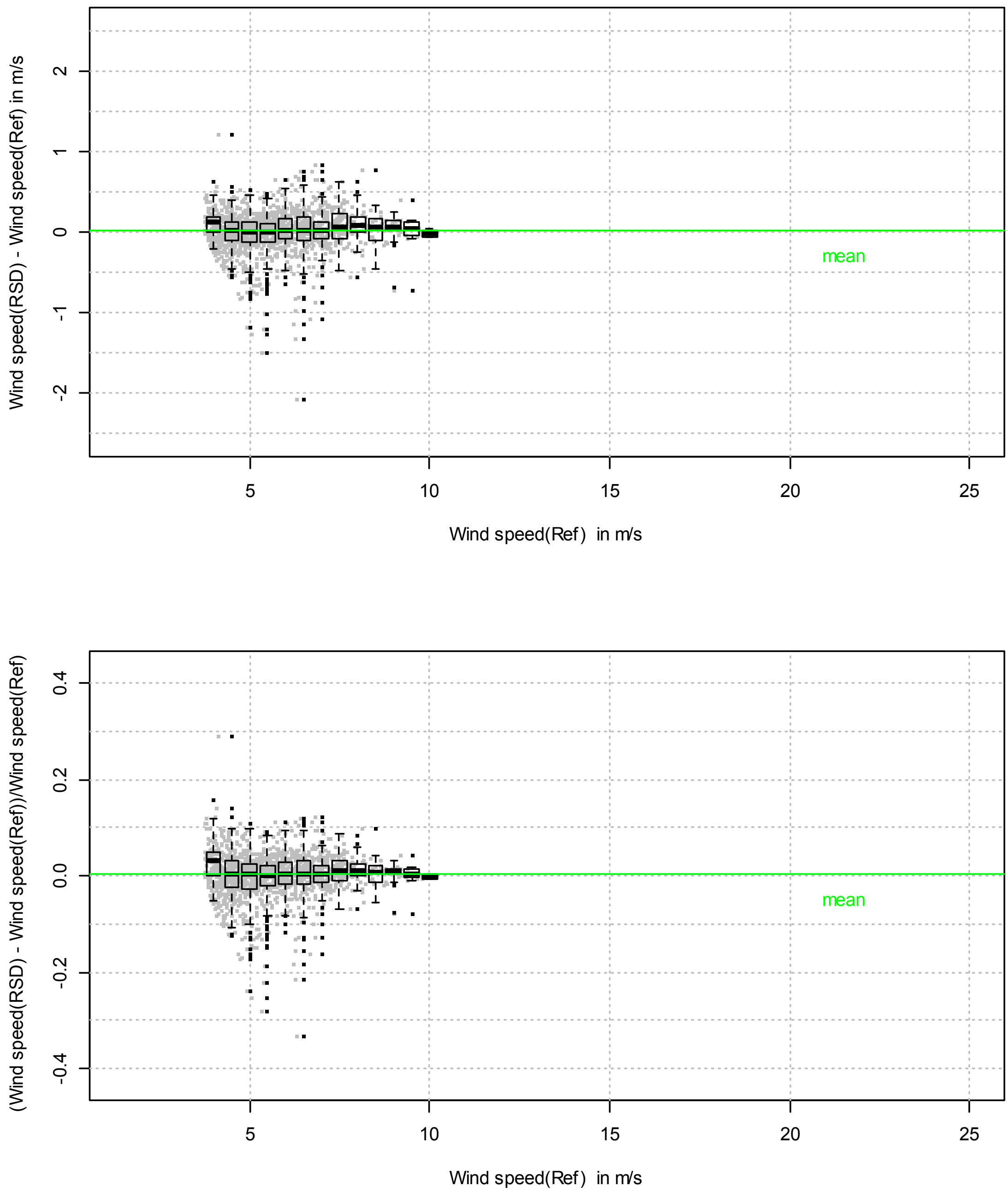
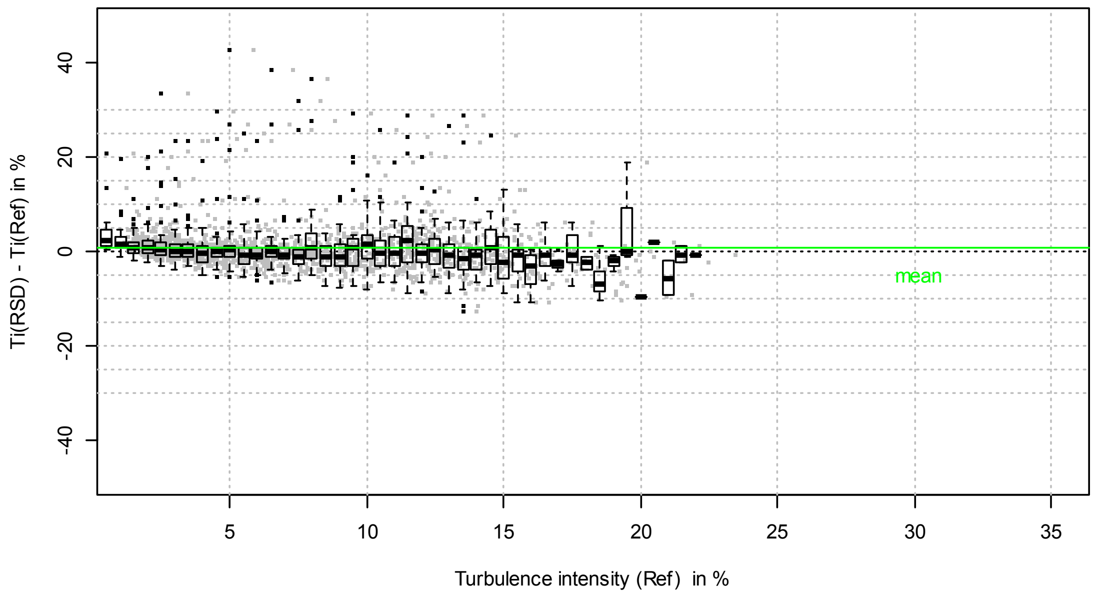


Fig. 21: Difference of wind speed between RSD and reference data versus reference data in m/s: (Upper) absolute difference in m/s; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



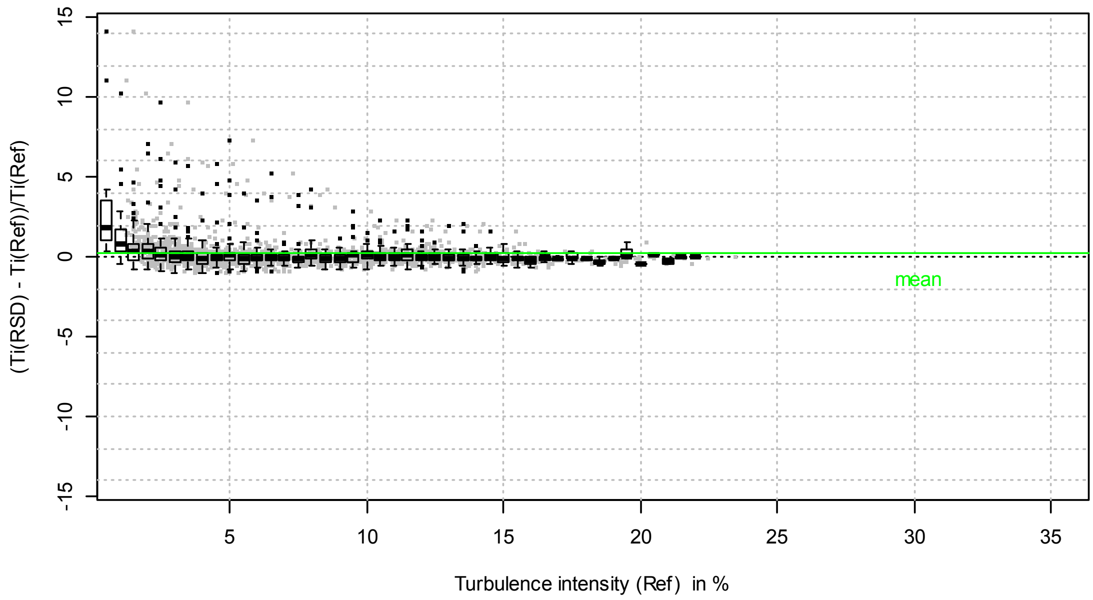
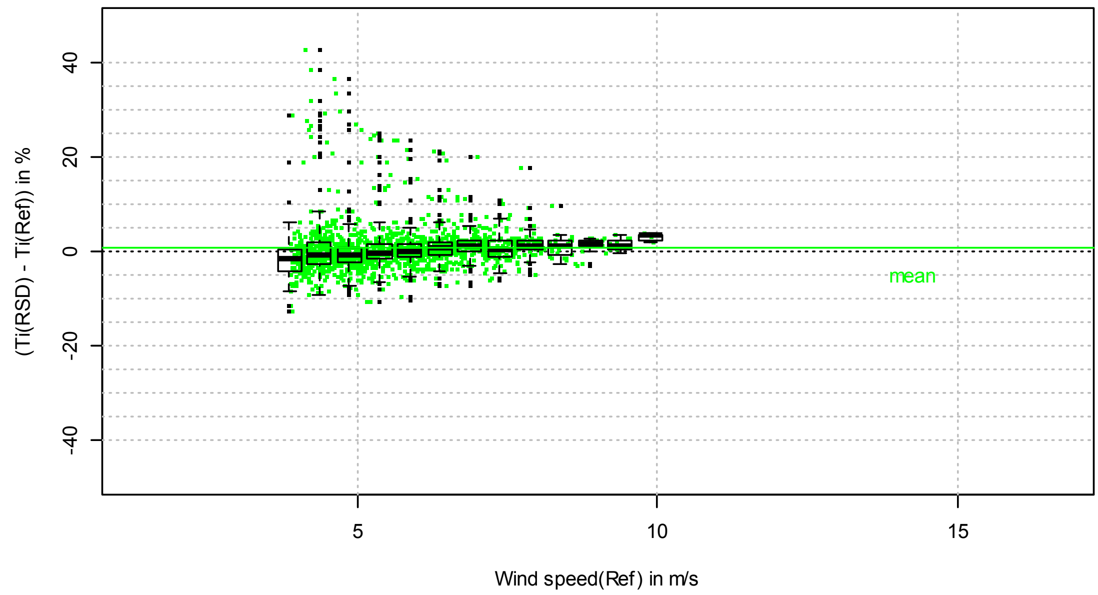


Fig. 22: Difference of turbulence intensity between RSD and reference data versus reference turbulence intensity in %: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



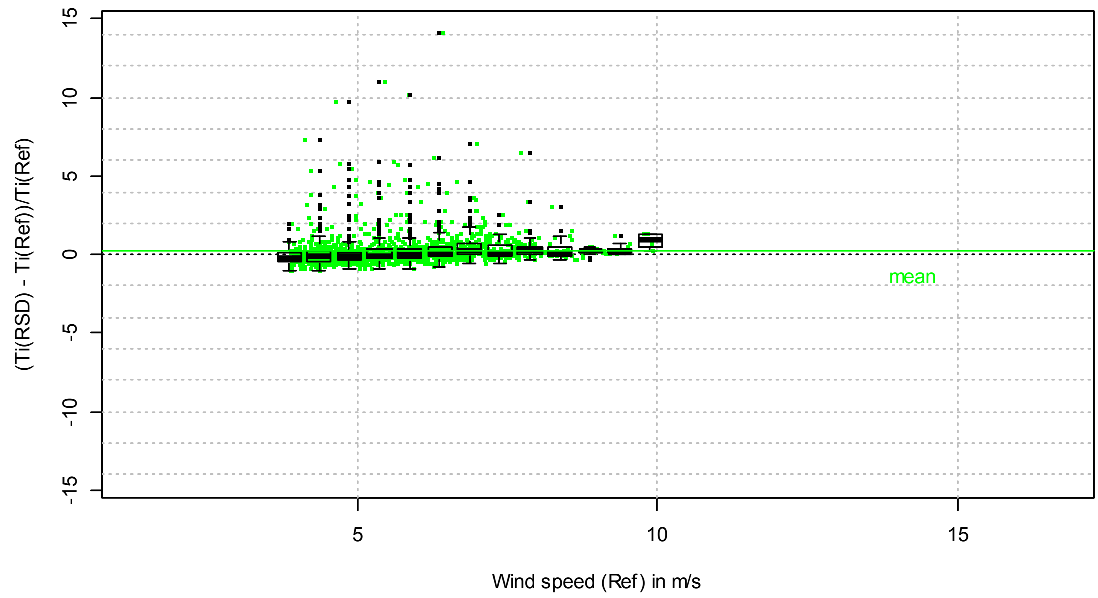
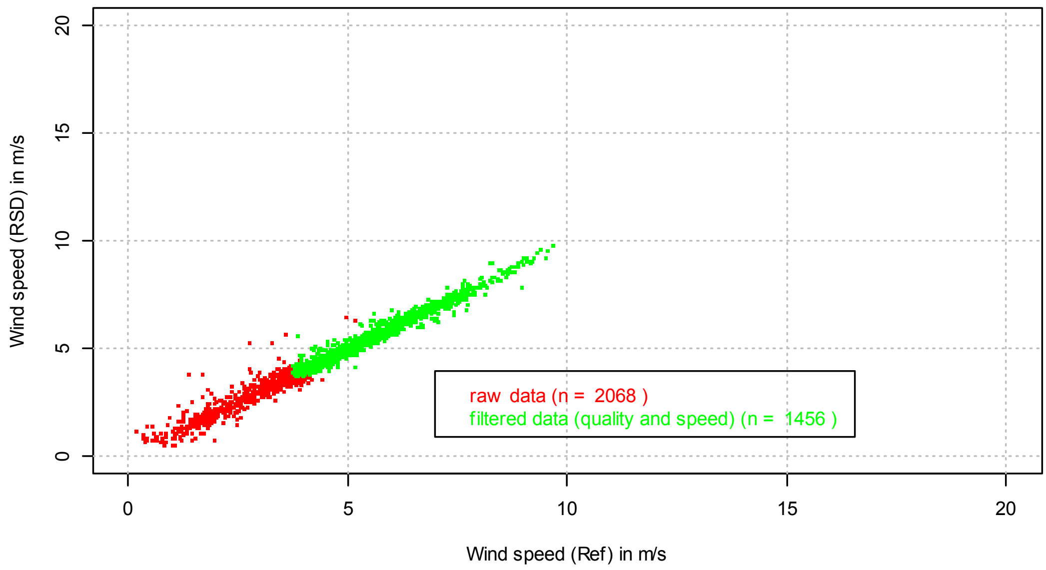


Fig. 23: Difference of turbulence intensity between RSD and reference data versus reference data in m/s: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

5.3.2 Ten minute mean wind speed of the data at 100.9m

The results of the analysis comparing the reference data at anemometer V2 and the RSD data of the 100.7 m height measurement are shown in the following figures.



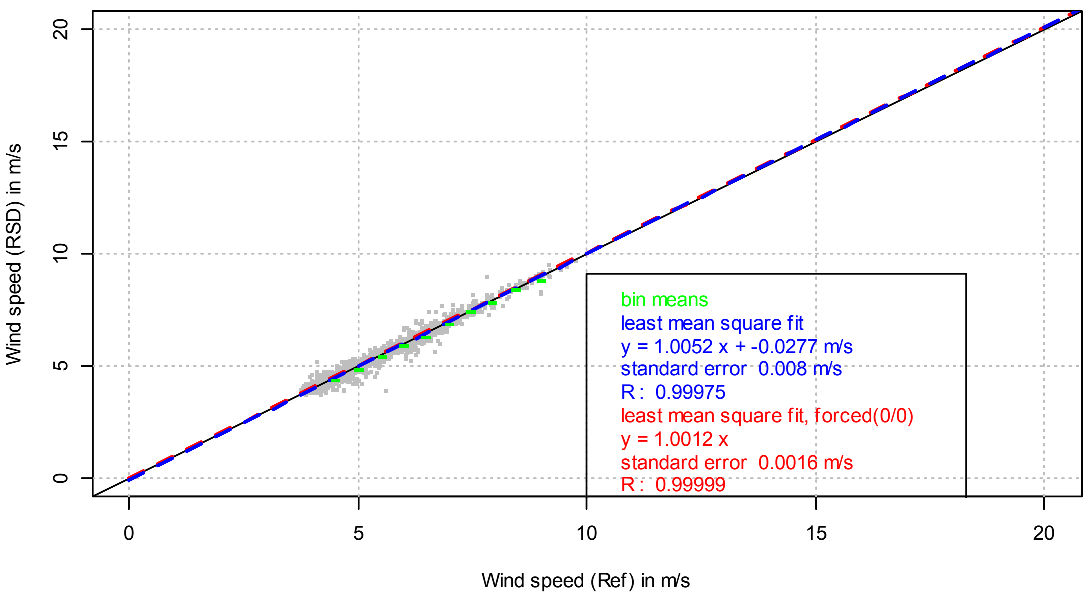
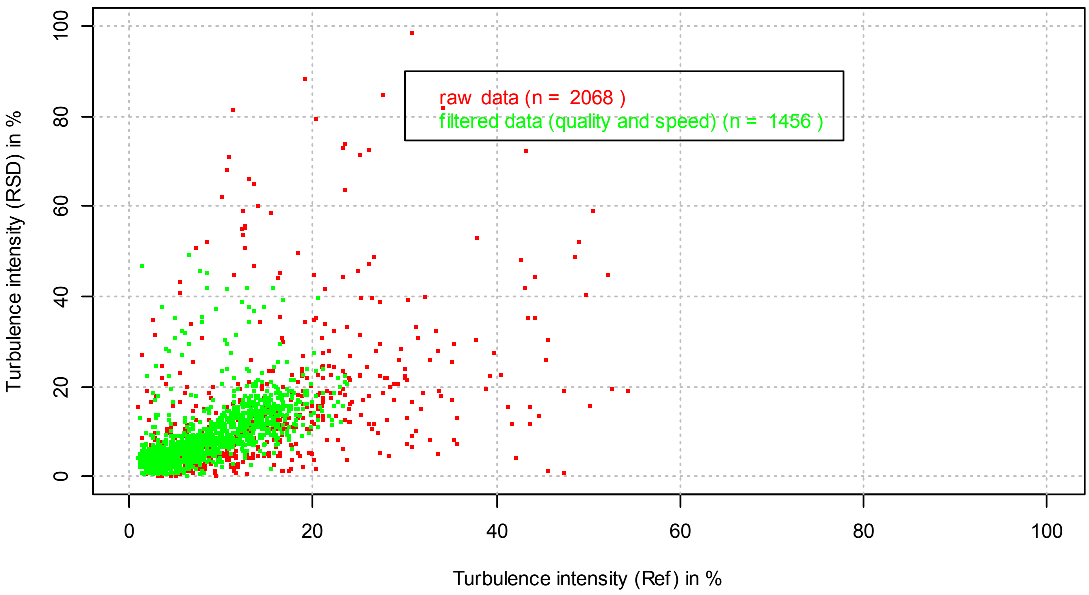


Fig. 24: Wind speed of the RSD (ordinate) versus wind speed reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



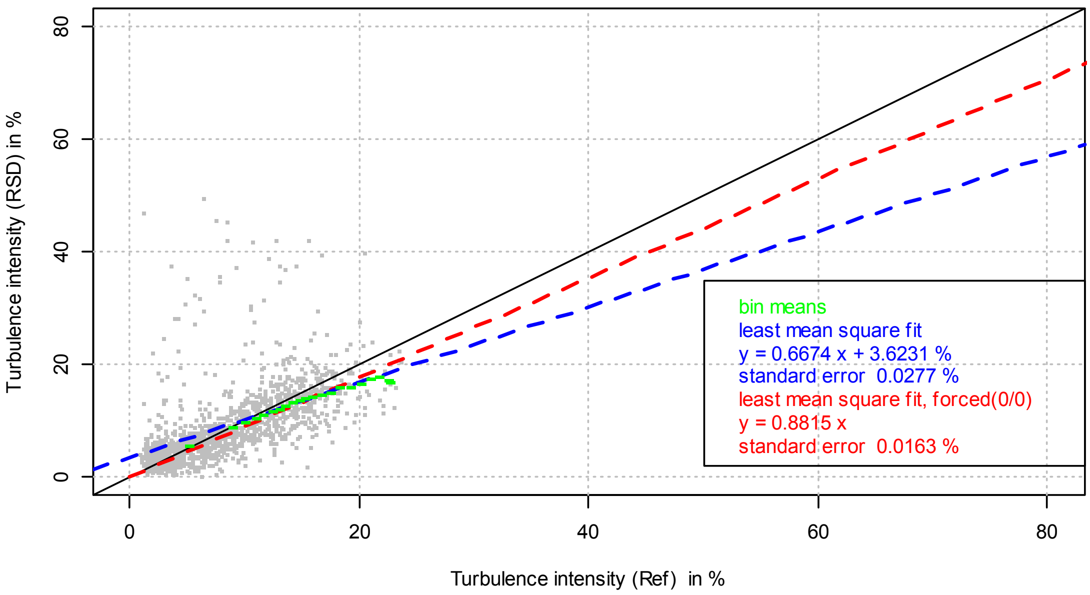
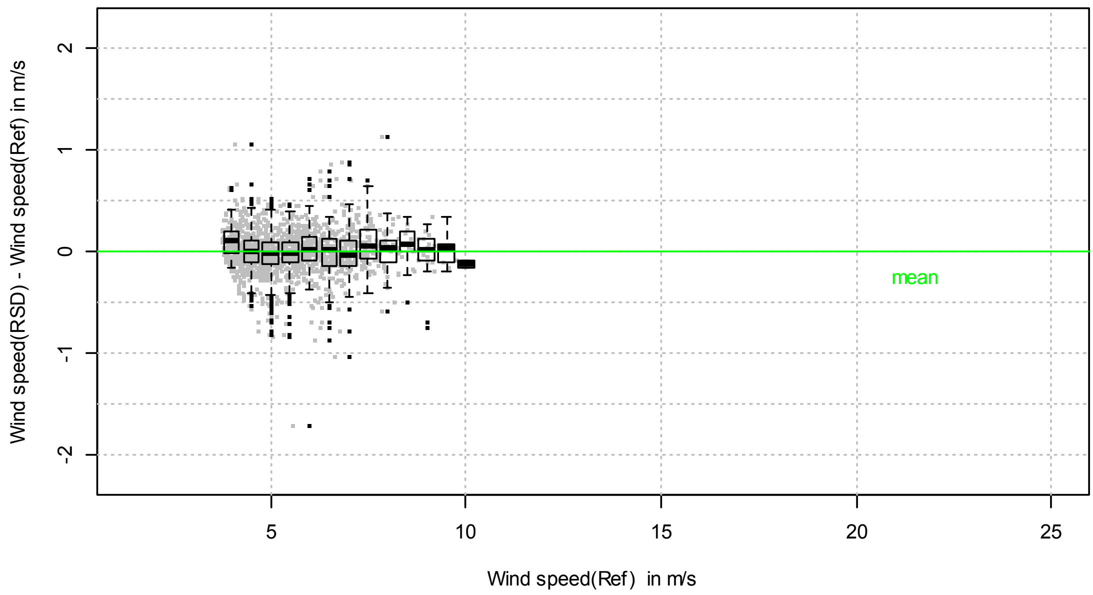


Fig. 25: Turbulence intensity of the RSD (ordinate) versus turbulence intensity reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



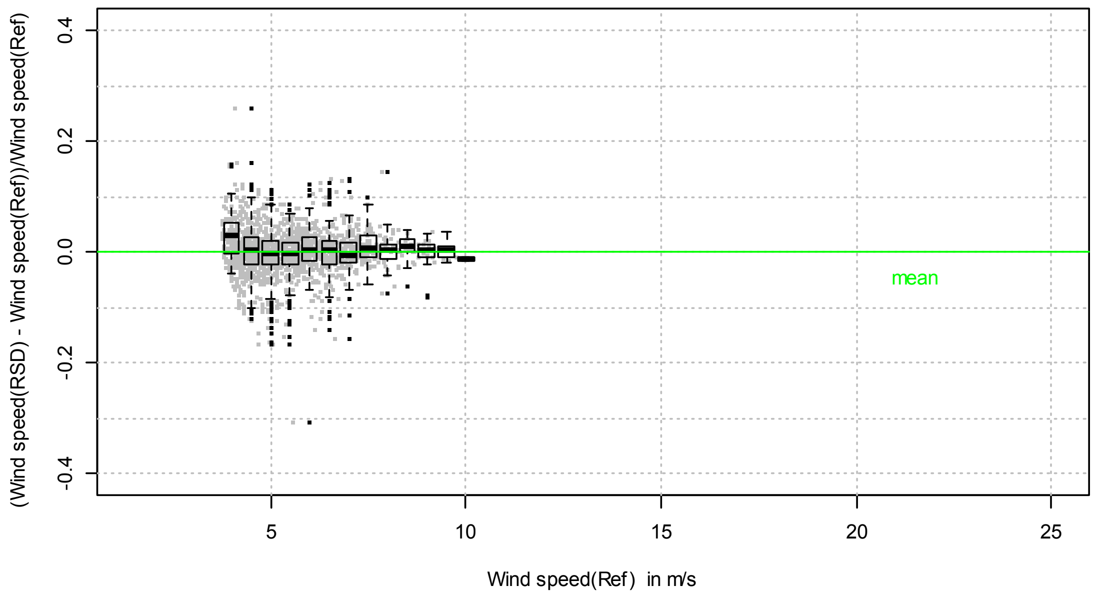
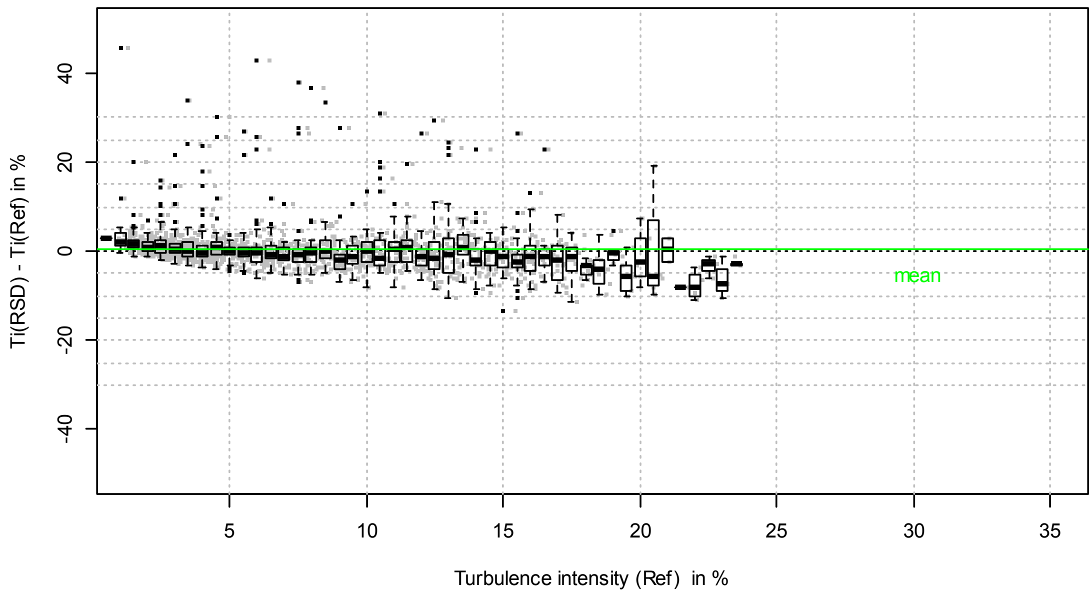


Fig. 26: Difference of wind speed between RSD and reference data versus reference data in m/s: (Upper) absolute difference in m/s; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



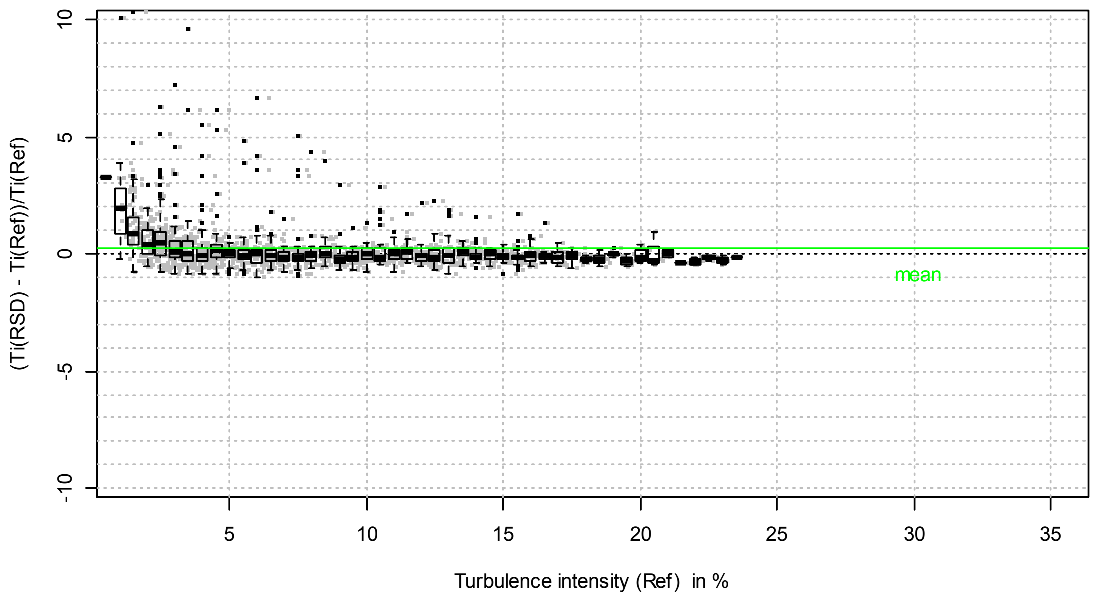


Fig. 27: Difference of turbulence intensity between RSD and reference data versus reference turbulence intensity in %: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

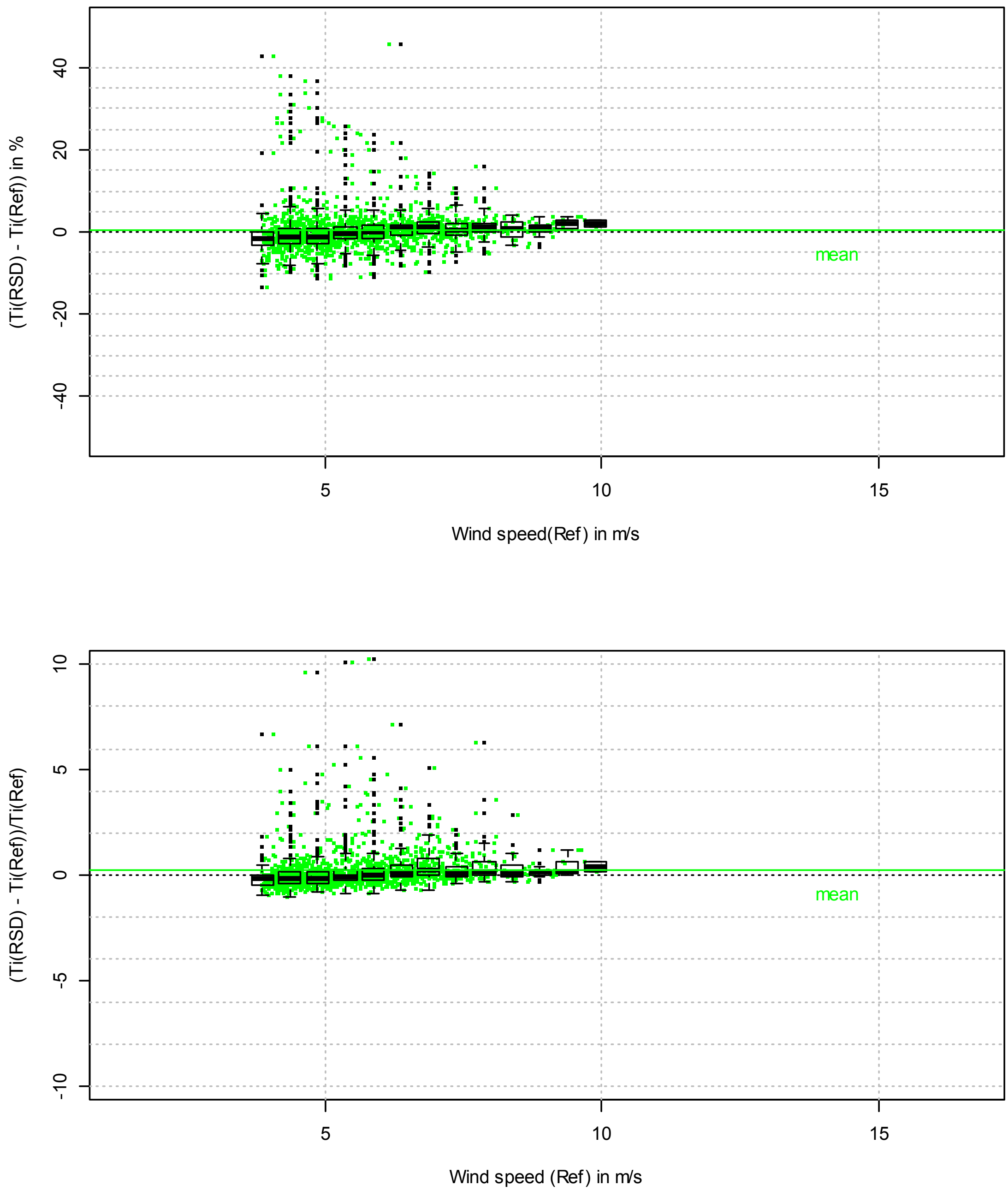
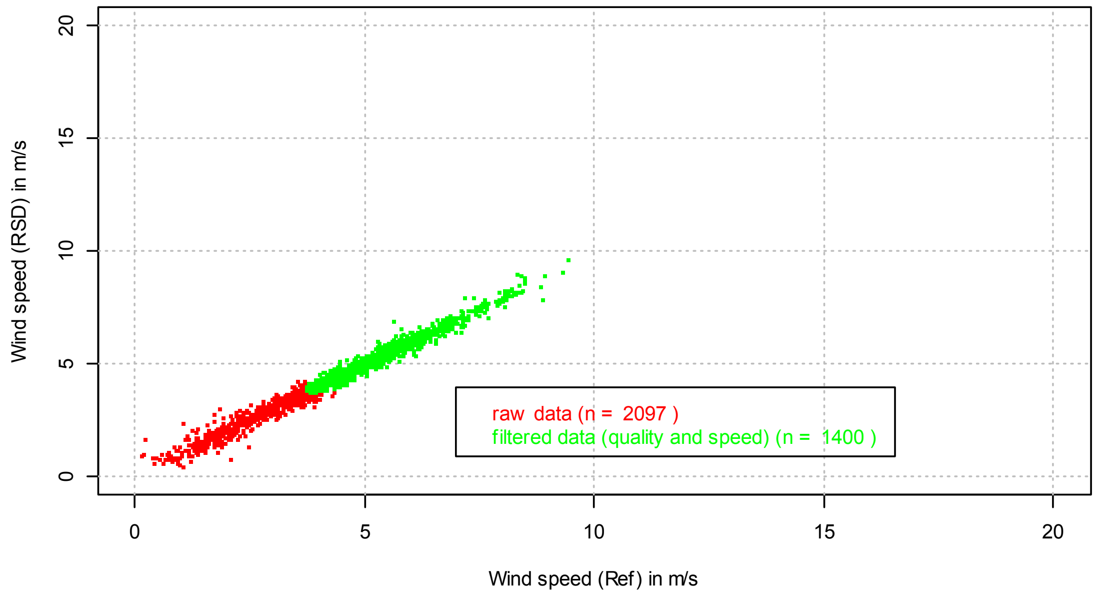


Fig. 28: Difference of turbulence intensity between RSD and reference data versus reference data in m/s: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

5.3.3 Ten minute mean wind speed of the data at 80.1 m

The results of the analysis comparing the reference data at anemometer V3 and the RSD data of the 80.7 m height measurement are shown in the following figures.



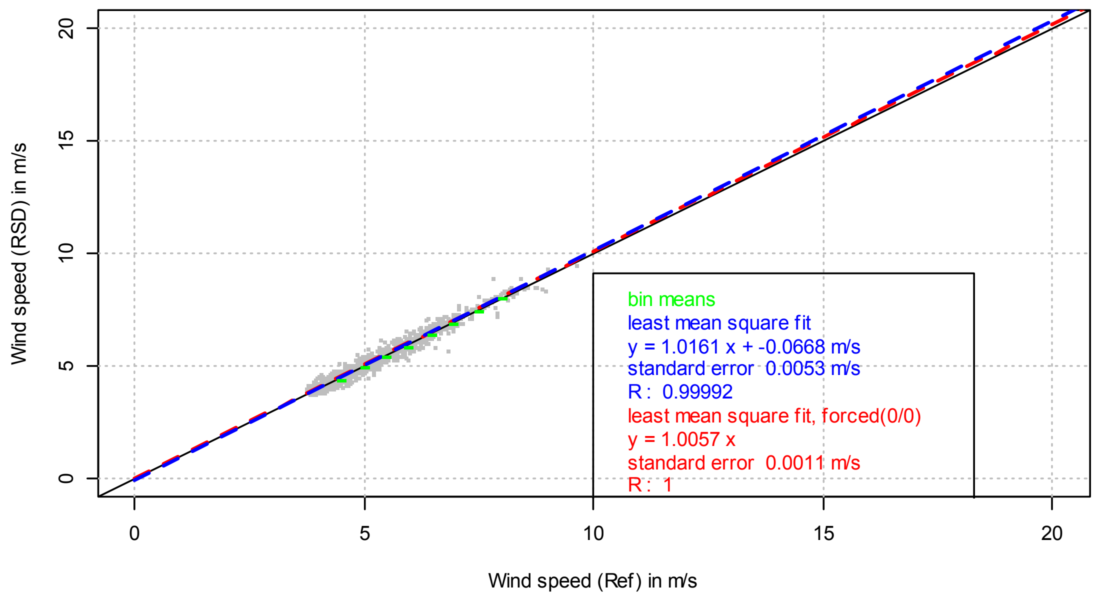
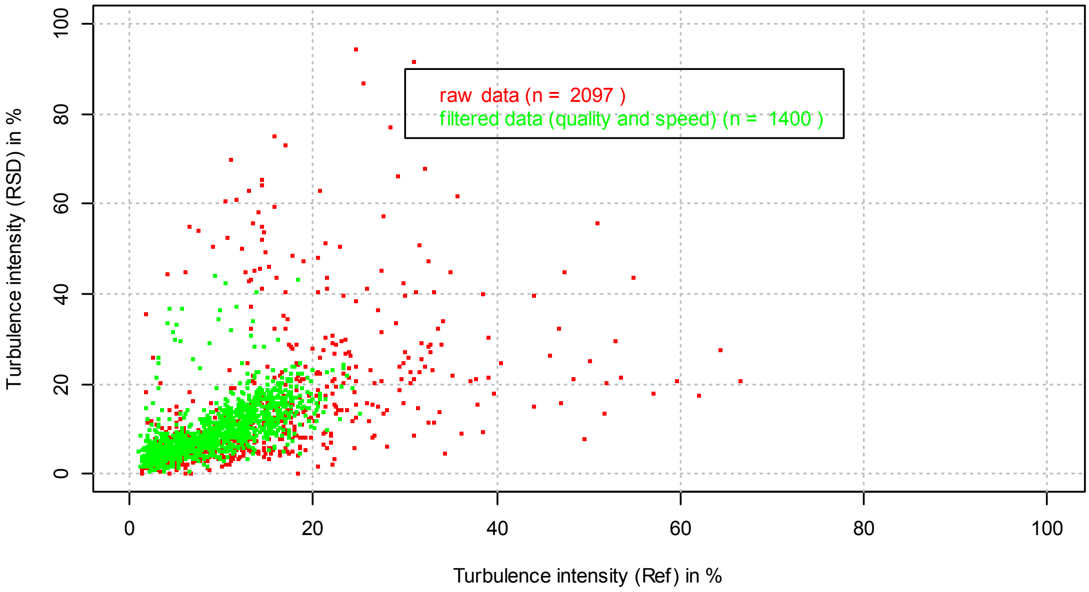


Fig. 29: Wind speed of the RSD (ordinate) versus wind speed reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



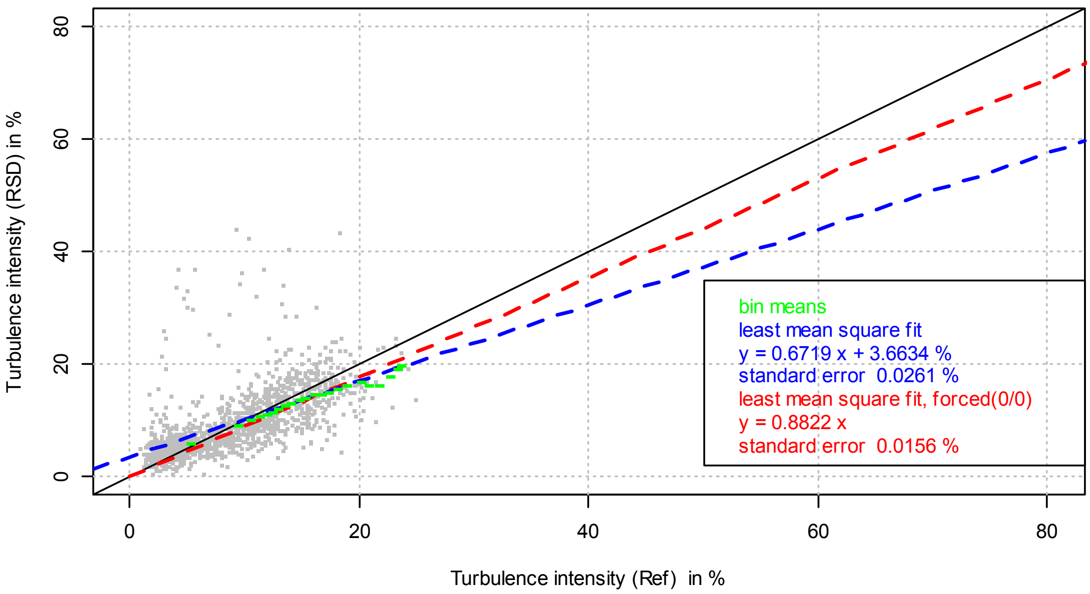


Fig. 30: Turbulence intensity of the RSD (ordinate) versus turbulence intensity reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.

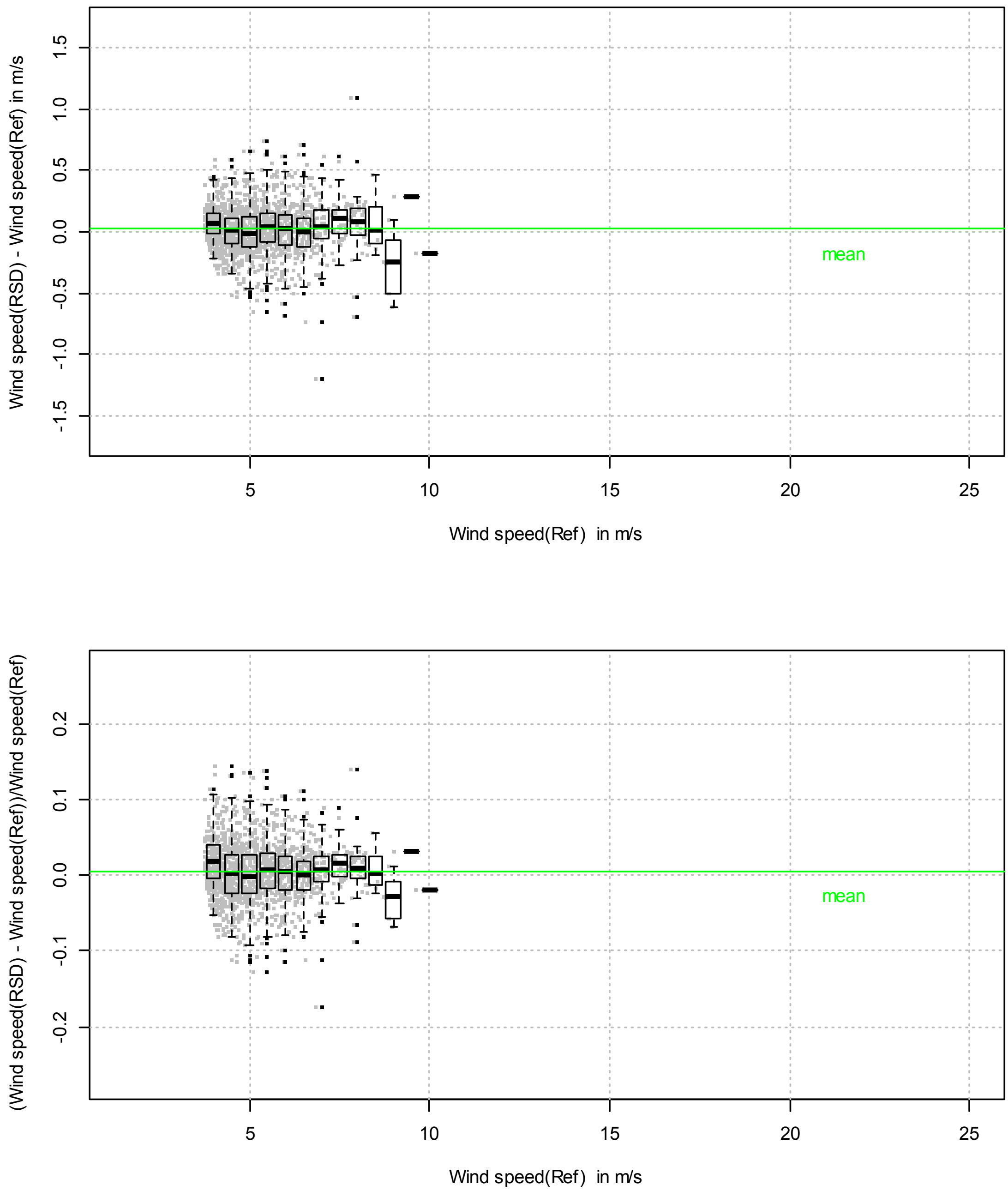
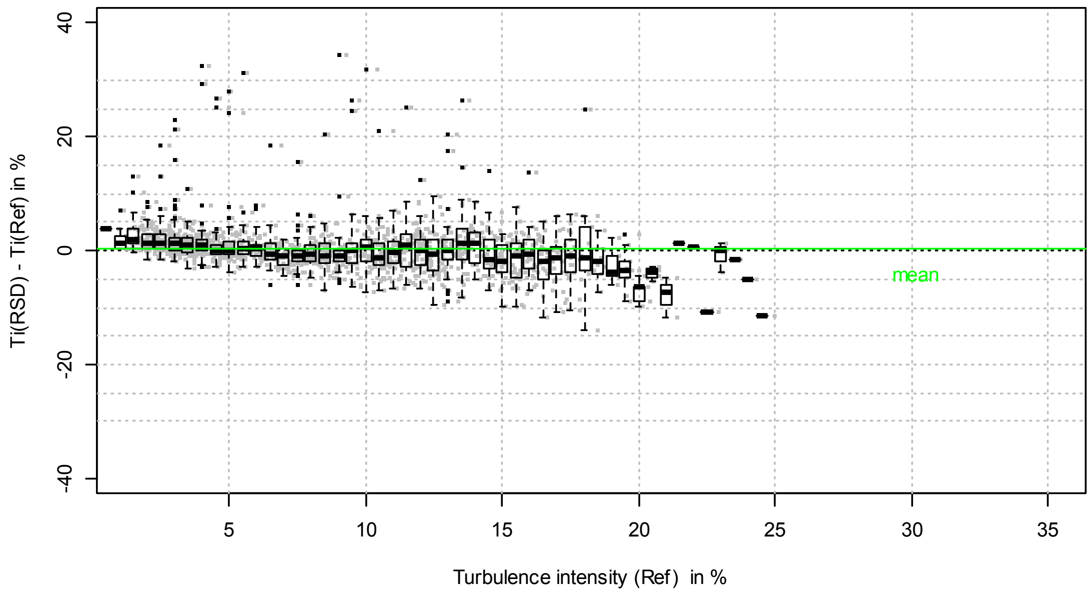


Fig. 31: Difference of wind speed between RSD and reference data versus reference data in m/s: (Upper) absolute difference in m/s; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



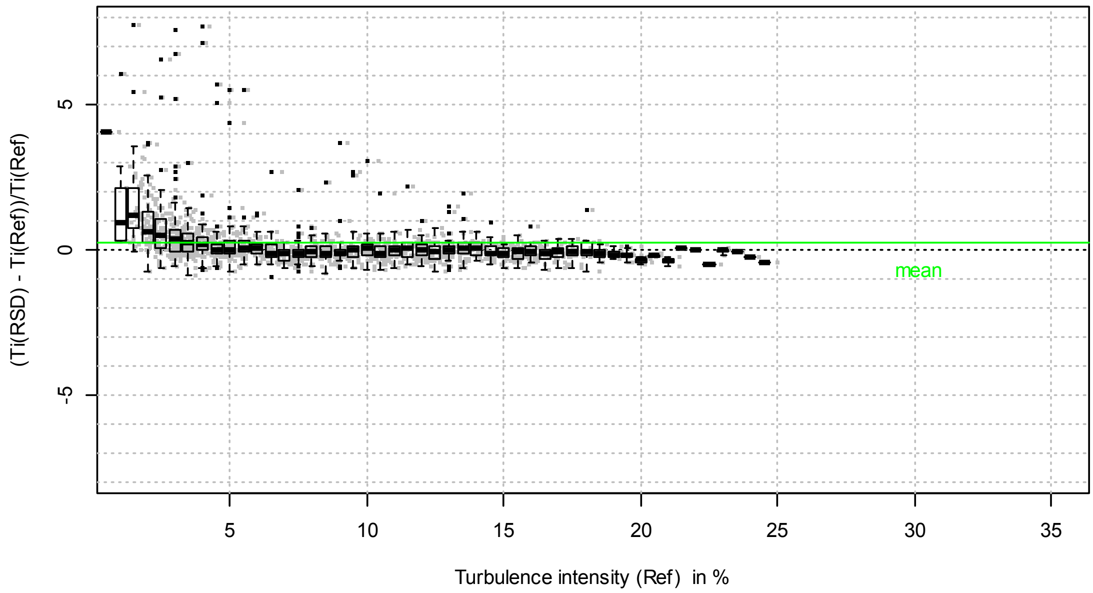
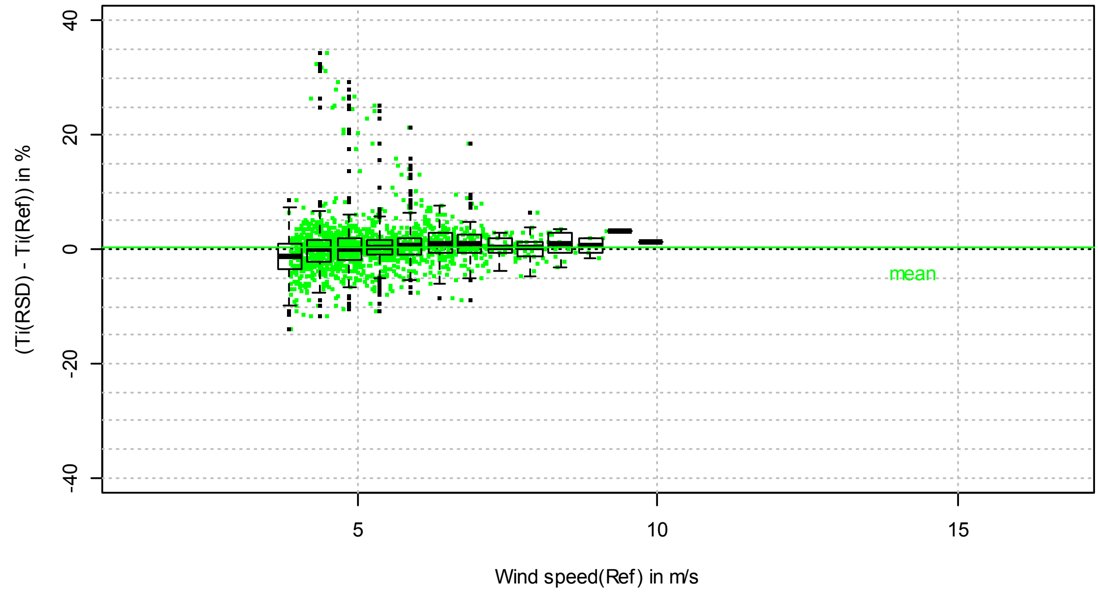


Fig. 32: Difference of turbulence intensity between RSD and reference data versus reference turbulence intensity in %: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



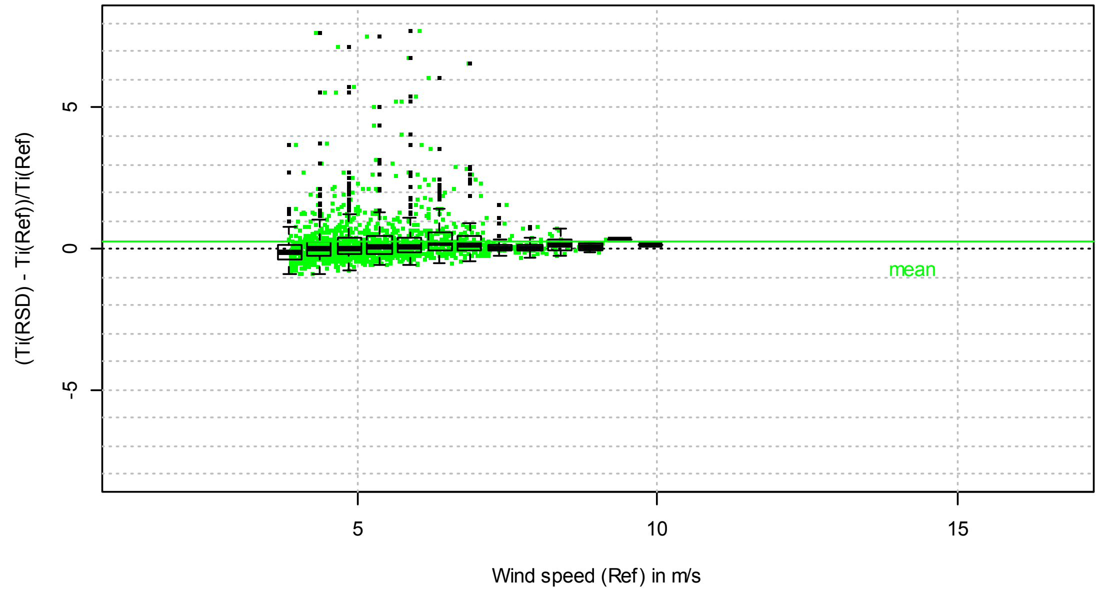
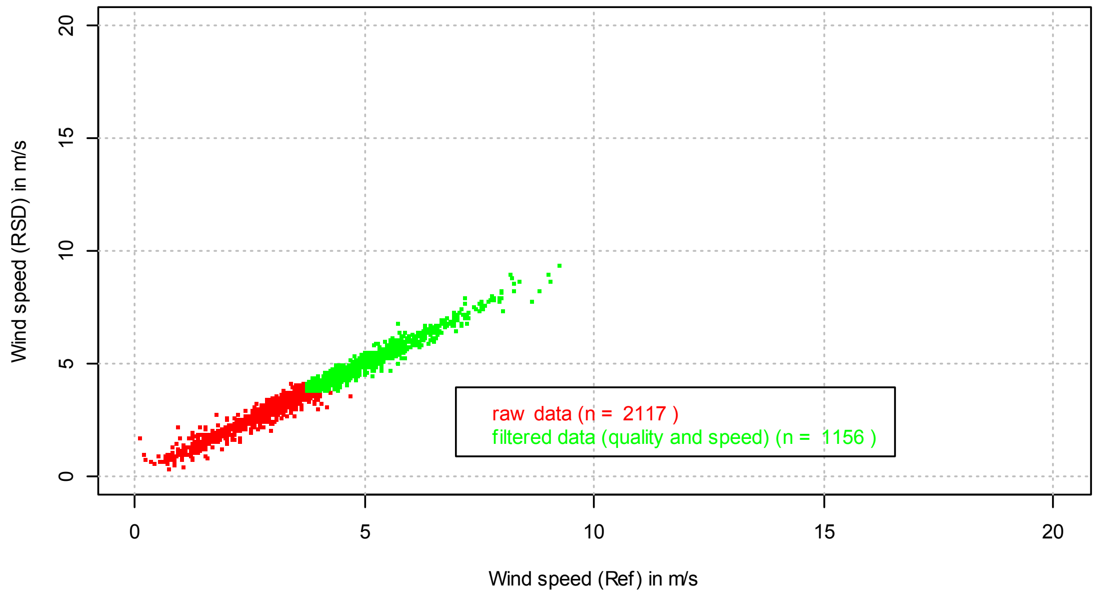


Fig. 33: Difference of turbulence intensity between RSD and reference data versus reference data in m/s: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

5.3.4 Ten minute mean wind speed of the data at 60.1 m

The results of the analysis comparing the reference data at anemometer V4 and the RSD data of the 60.7 m height measurement are shown in the following figures.



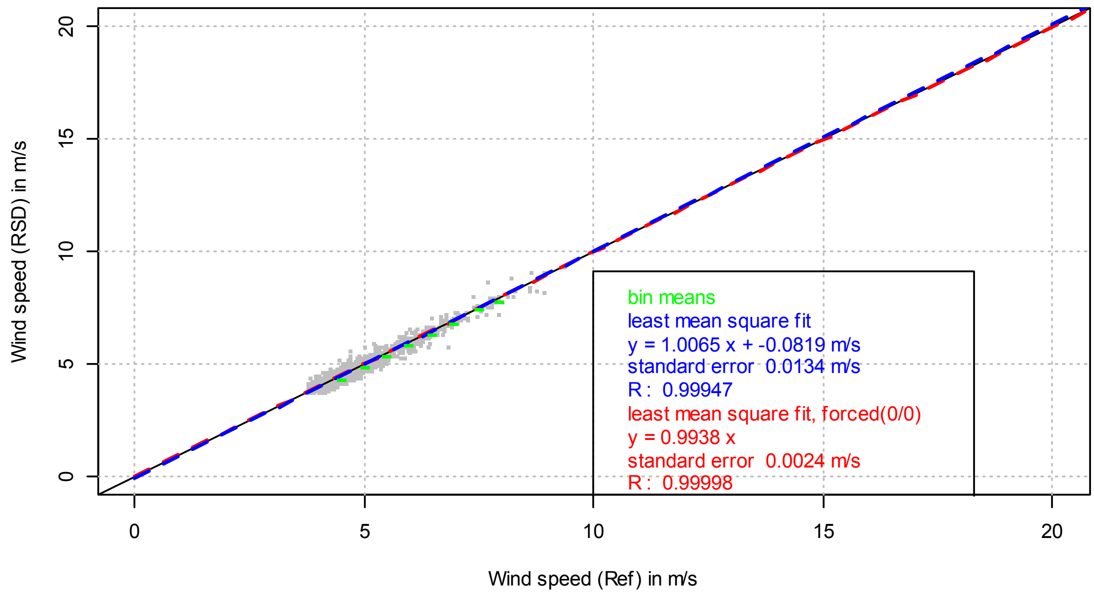
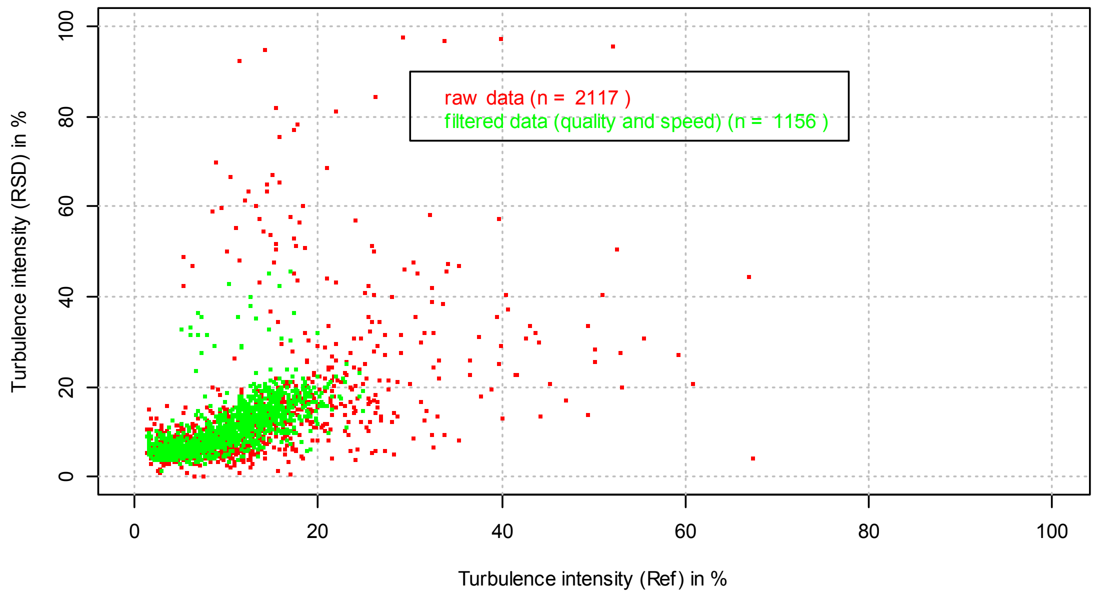


Fig. 34: Wind speed of the RSD (ordinate) versus wind speed reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



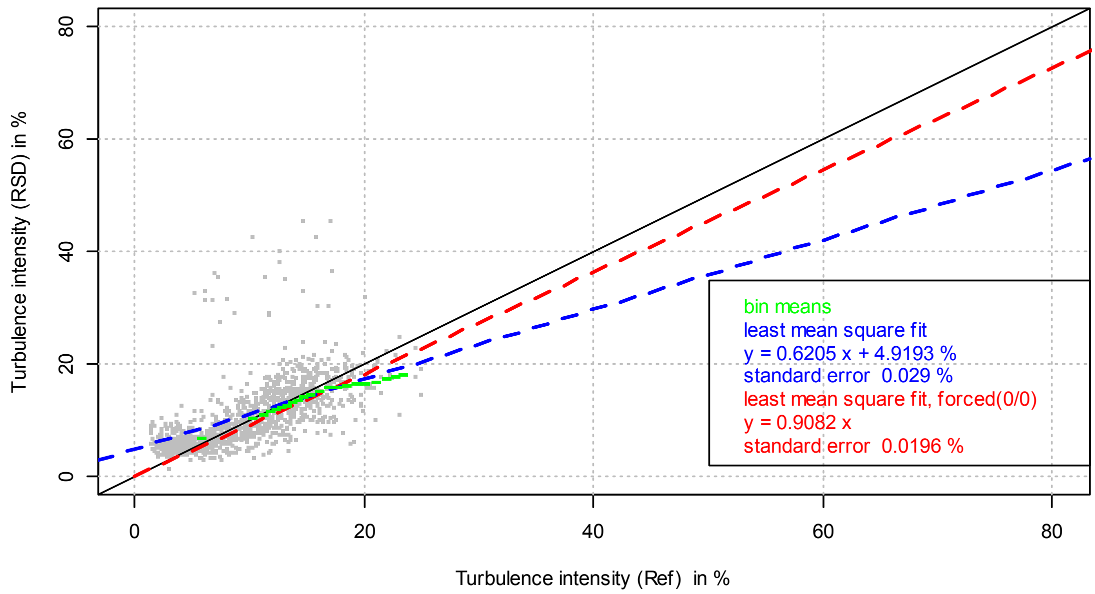
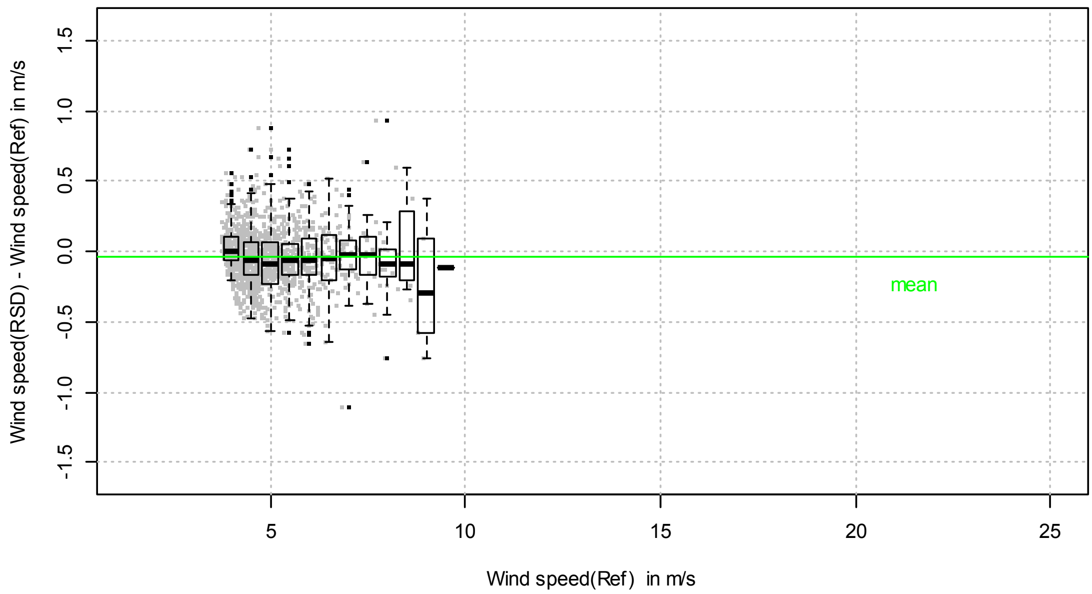


Fig. 35: Turbulence intensity of the RSD (ordinate) versus turbulence intensity reference mast (abscissa). (Upper) Red data points represent unfiltered data and green points the filtered data. (Lower) Ordinary least square (OLS) fit based on the bin means. Blue shows the OLS fit not forced and red a forced OLS fit through origin.



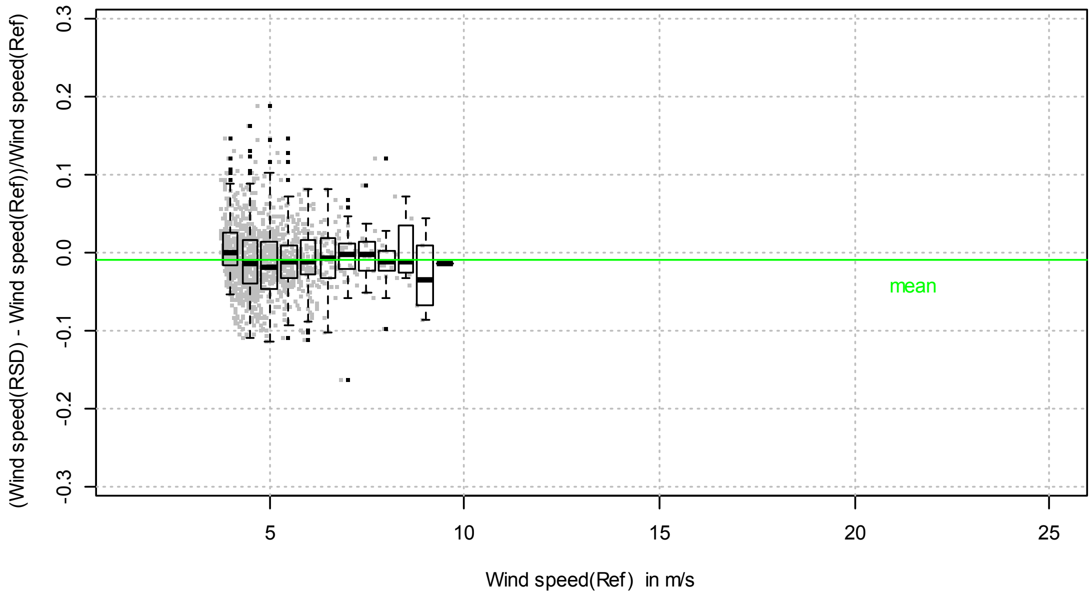
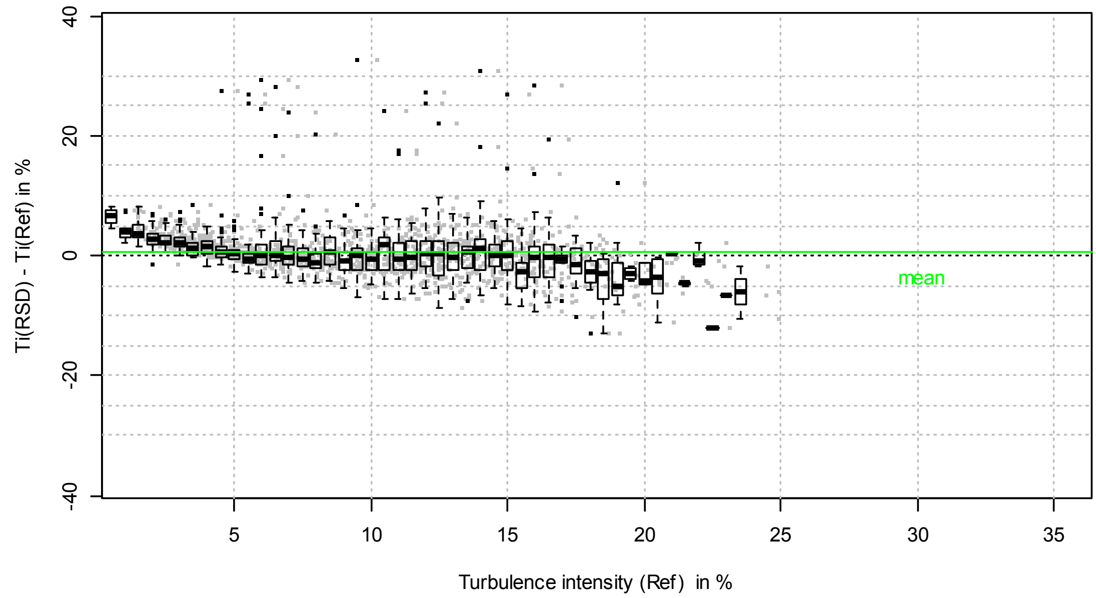


Fig. 36: Difference of wind speed between RSD and reference data versus reference data in m/s: (Upper) absolute difference in m/s; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.



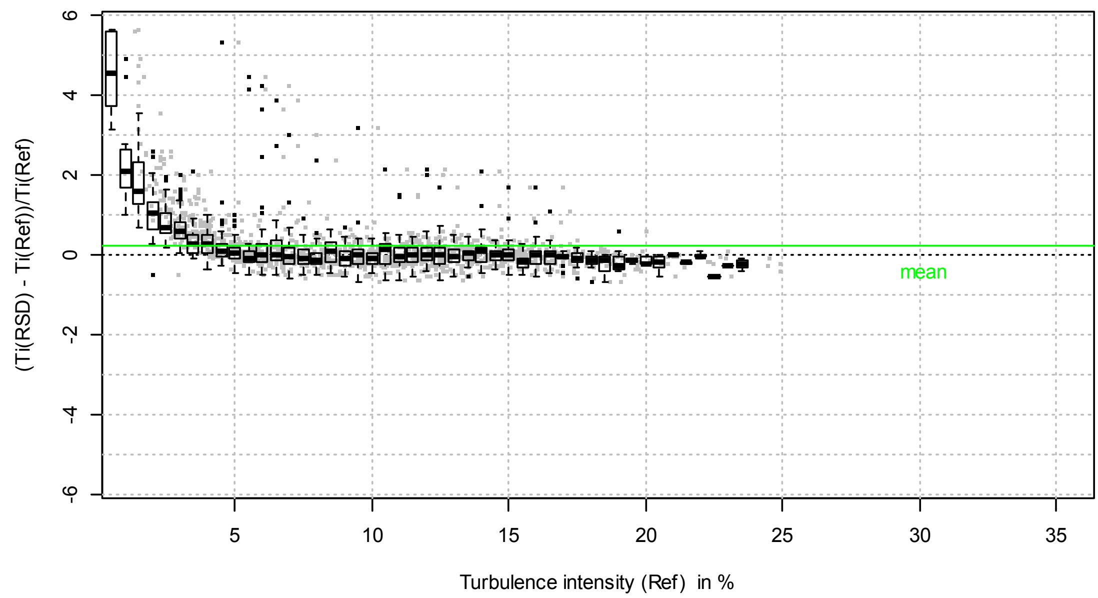


Fig. 37: Difference of turbulence intensity between RSD and reference data versus reference turbulence intensity in %: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

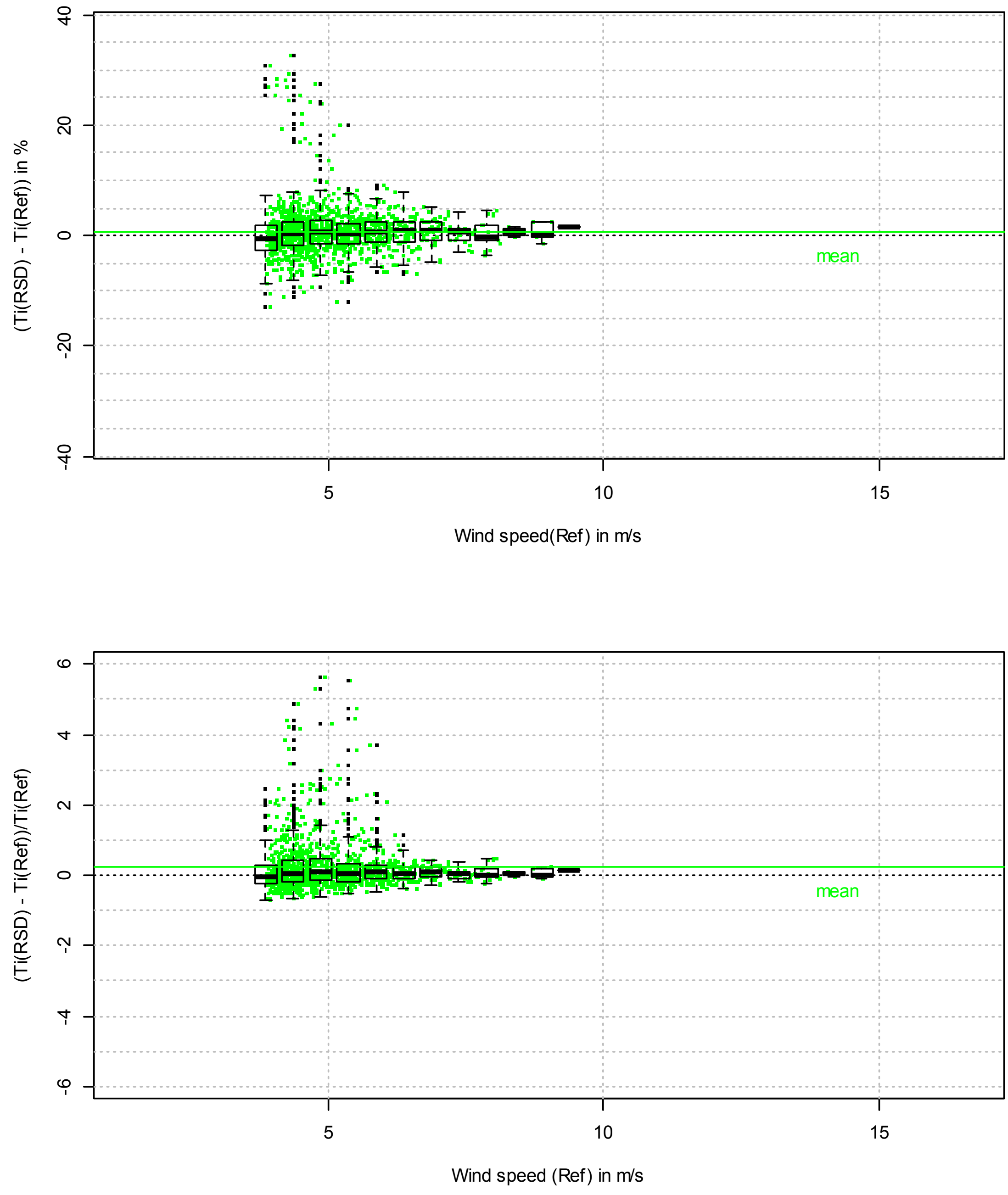
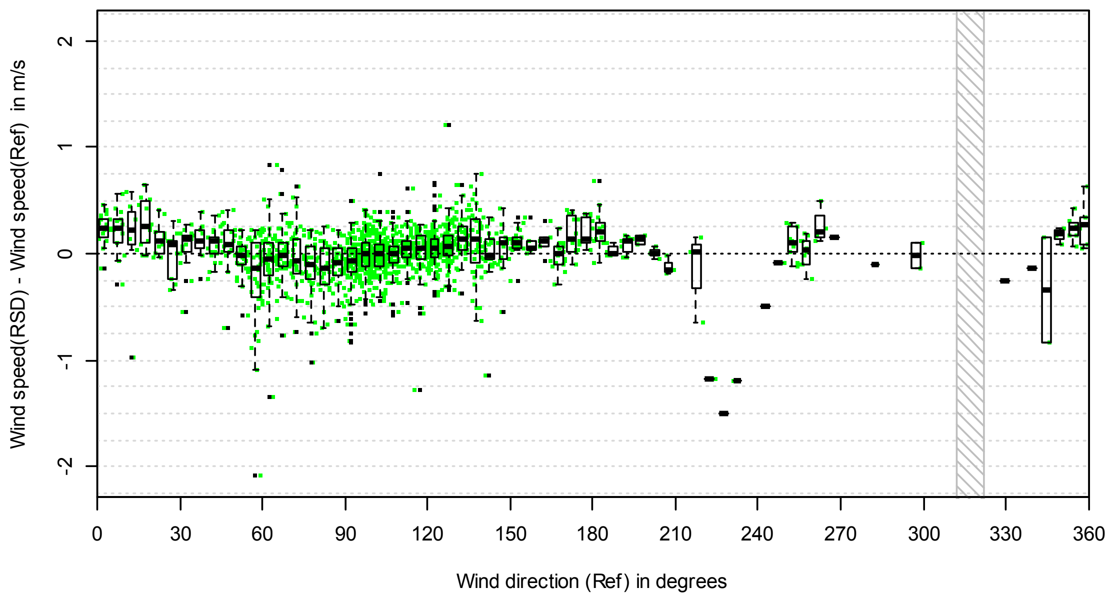


Fig. 38: Difference of turbulence intensity between RSD and reference data versus reference data in m/s: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points.

5.4 Wind direction distribution

5.4.1 Distribution of ten minute mean wind at V1 (wind vane D1 at 97.1 m)



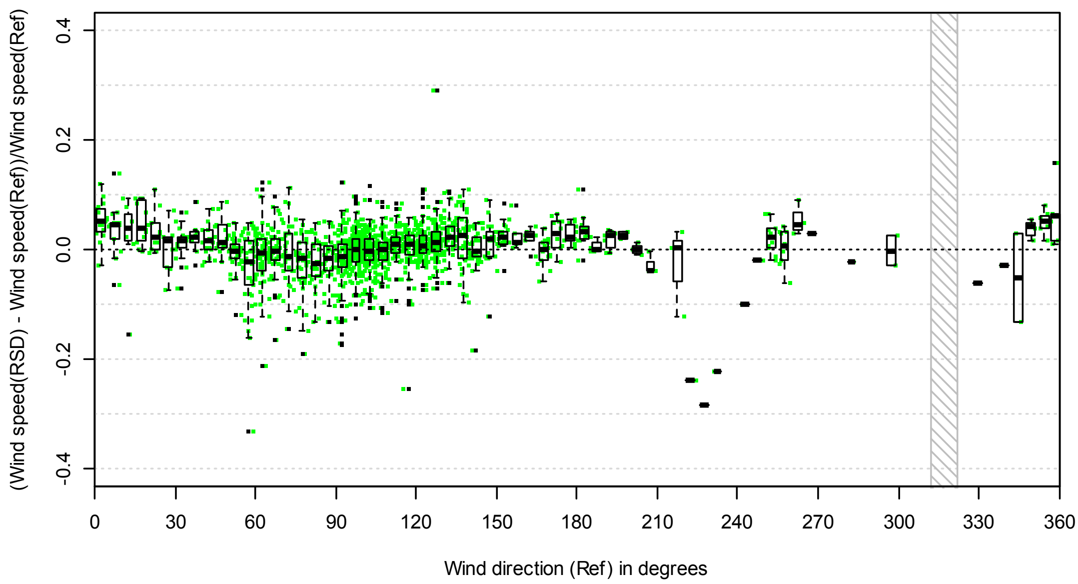
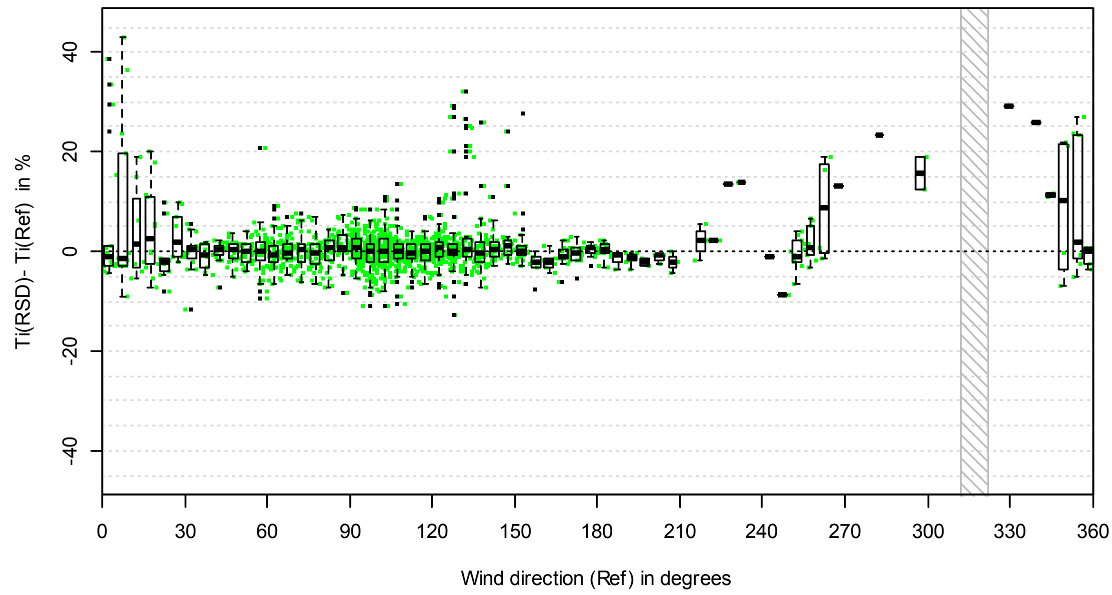


Fig. 39: Difference of wind speed between RSD and reference data versus reference direction in degrees: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 103.8 m (V1) at the reference mast, 105.7 m at the RSD and the wind vane at 97.1 m (D1) height.



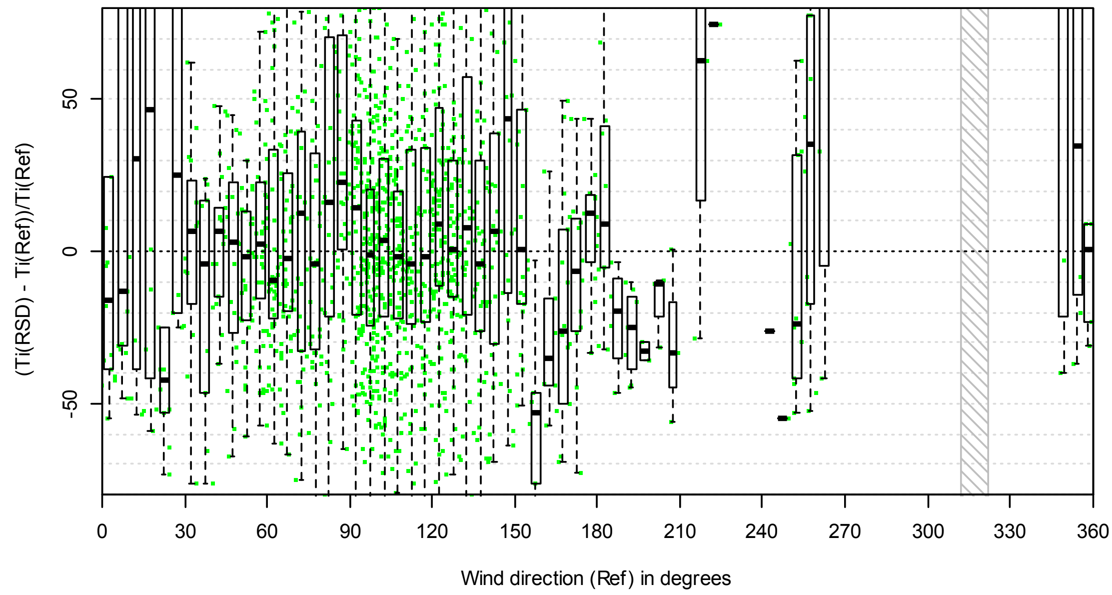
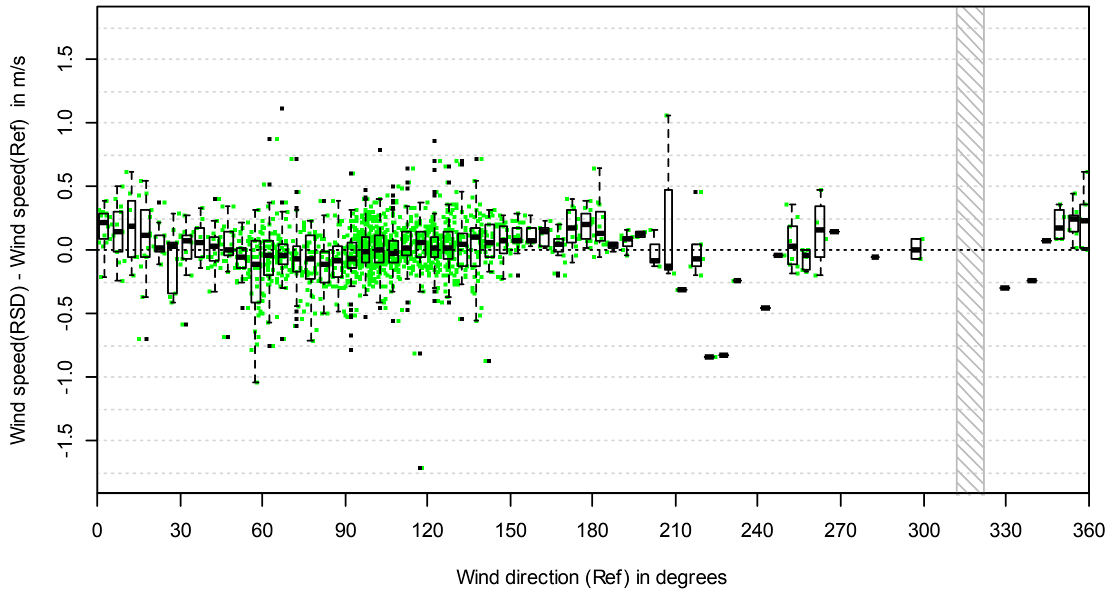


Fig. 40: Difference of turbulence intensity between RSD and reference data versus reference direction in degrees: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 103.8 m (V1) at the reference mast, 105.7 m at the RSD and the wind vane at 97.1 m (D1) height.

5.4.2 Distribution of ten minute mean wind at 100 m (wind vane D1 at 97.1 m)



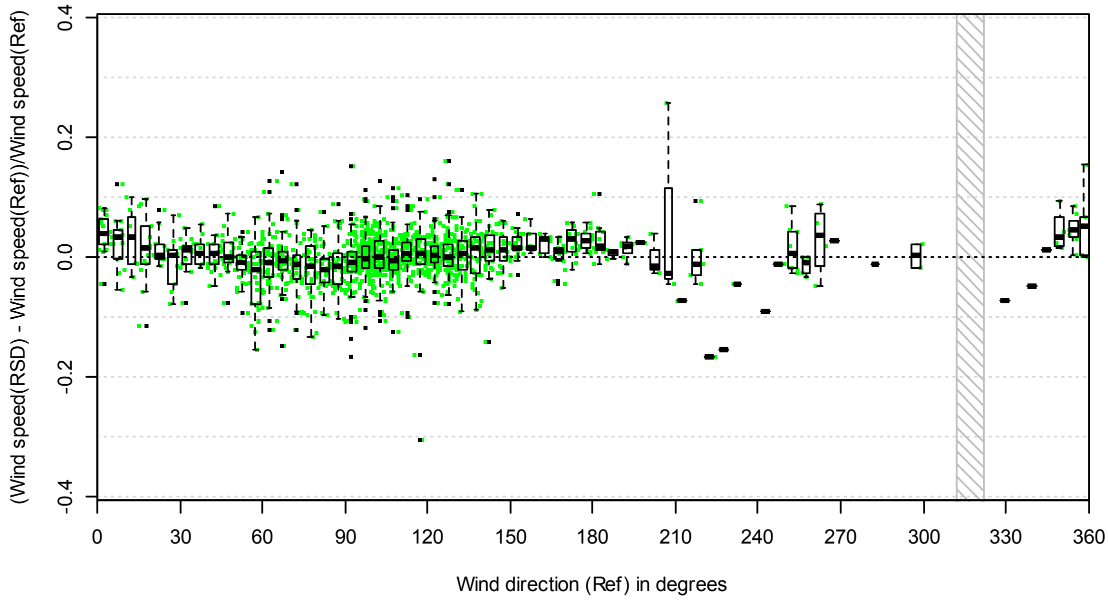
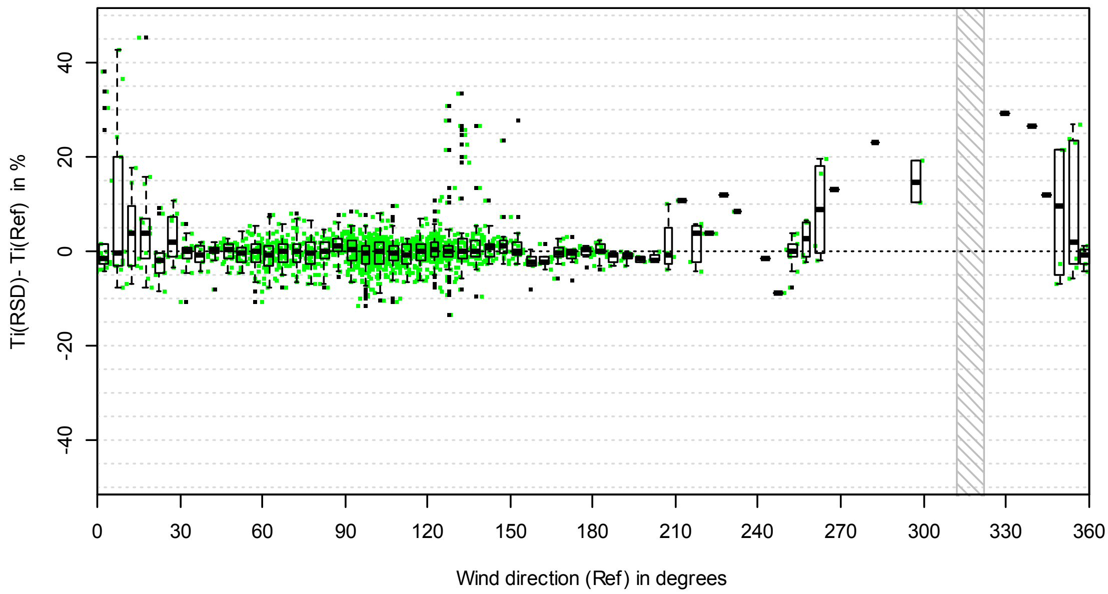


Fig. 41: Difference of wind speed between RSD and reference data versus reference direction in degrees at: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 100.9 m (V2) at the reference mast, 100.7 m at the RSD and the wind vane at 97.1 m (D1) height.



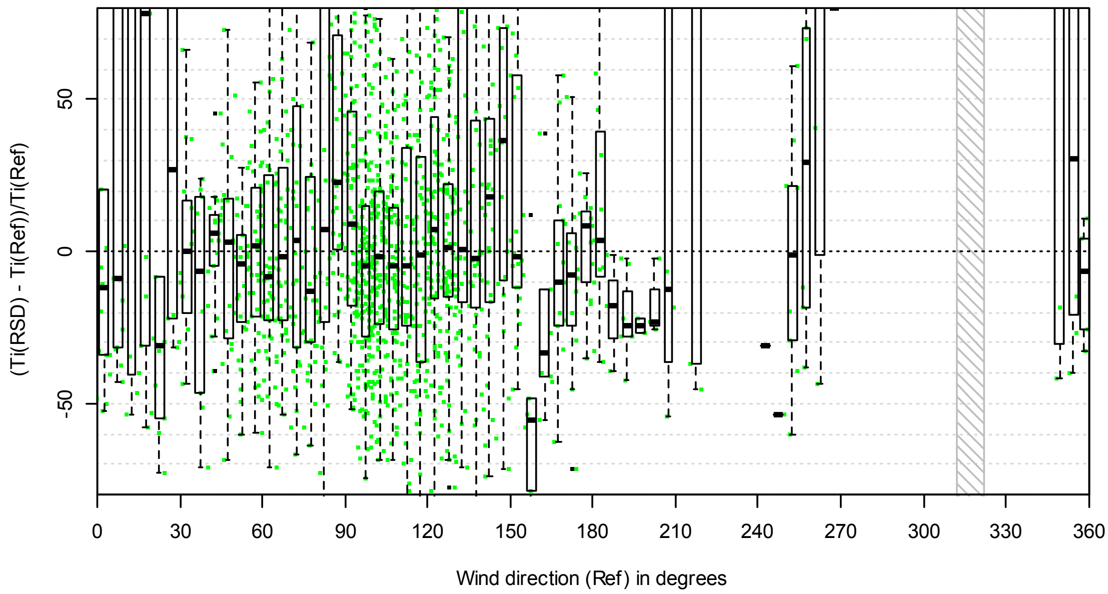
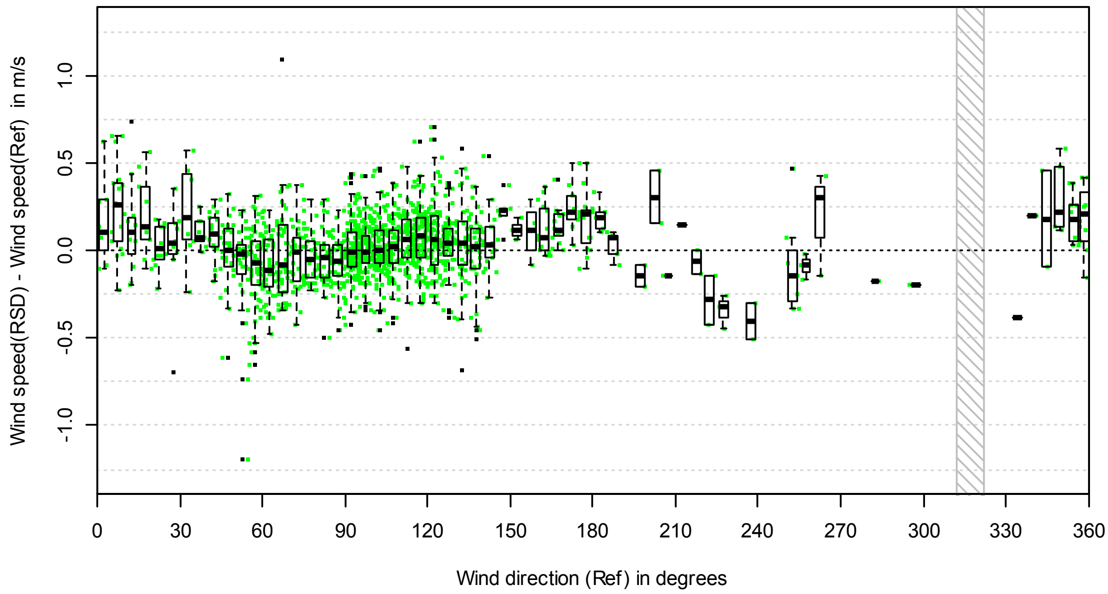


Fig. 42: Difference of turbulence intensity between RSD and reference data versus reference direction in degrees at: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 100.9 m (V2) at the reference mast, 100.7 m at the RSD and the wind vane at 97.1 m (D1) height.

5.4.3 Distribution of ten minute mean wind at V3 (wind vane D2 at 75.1 m)



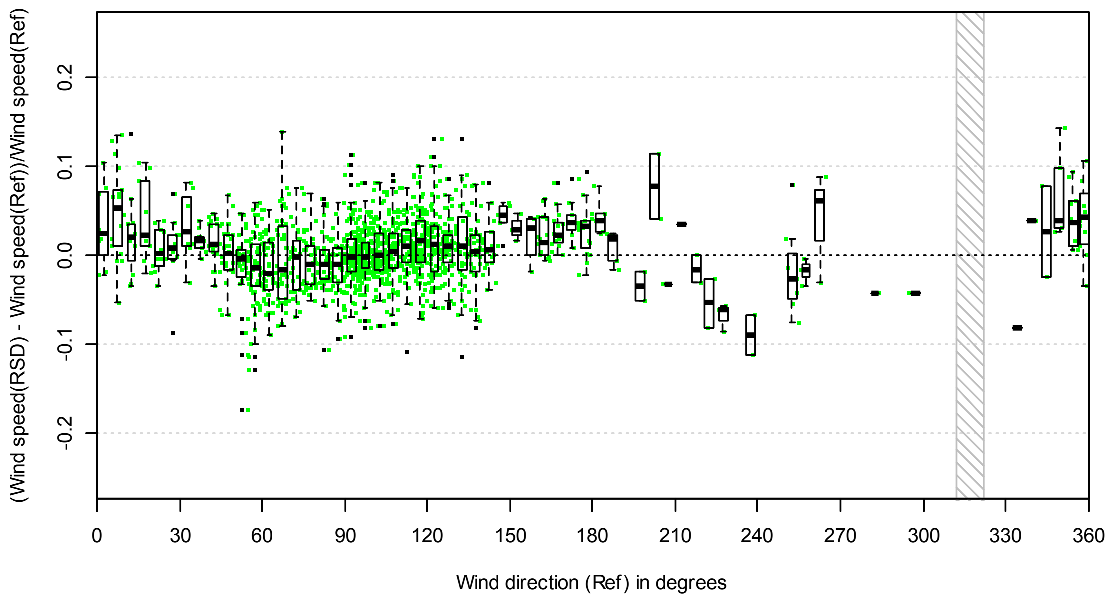
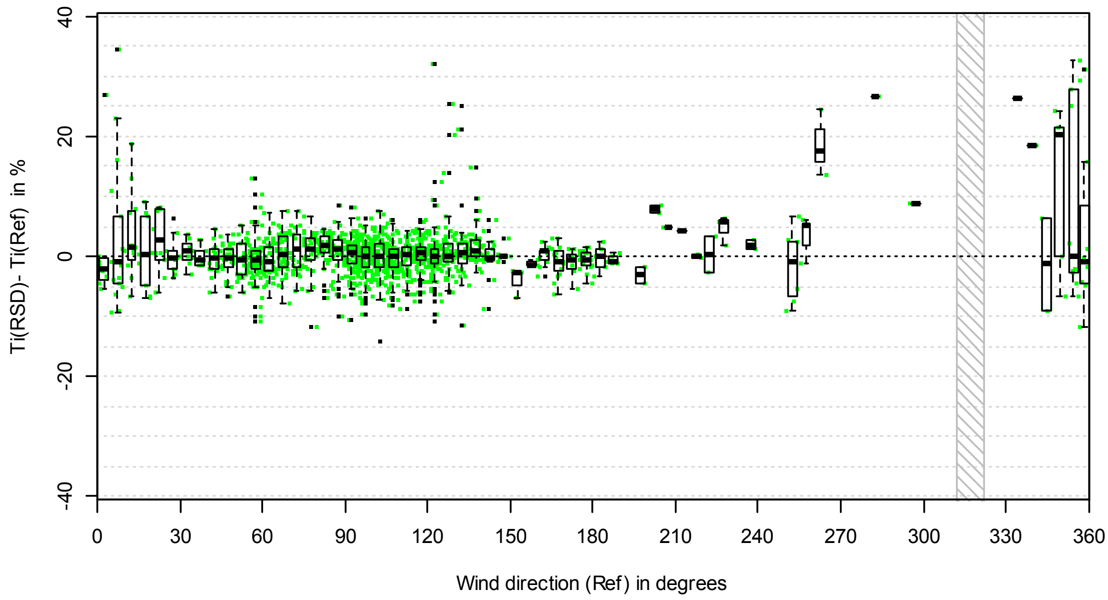


Fig. 43: Difference of wind speed between RSD and reference data versus reference direction in degrees at: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 80.1 m (V3) at the reference mast, 80.7 m at the RSD and the wind vane at 75.1 m (D2) height.



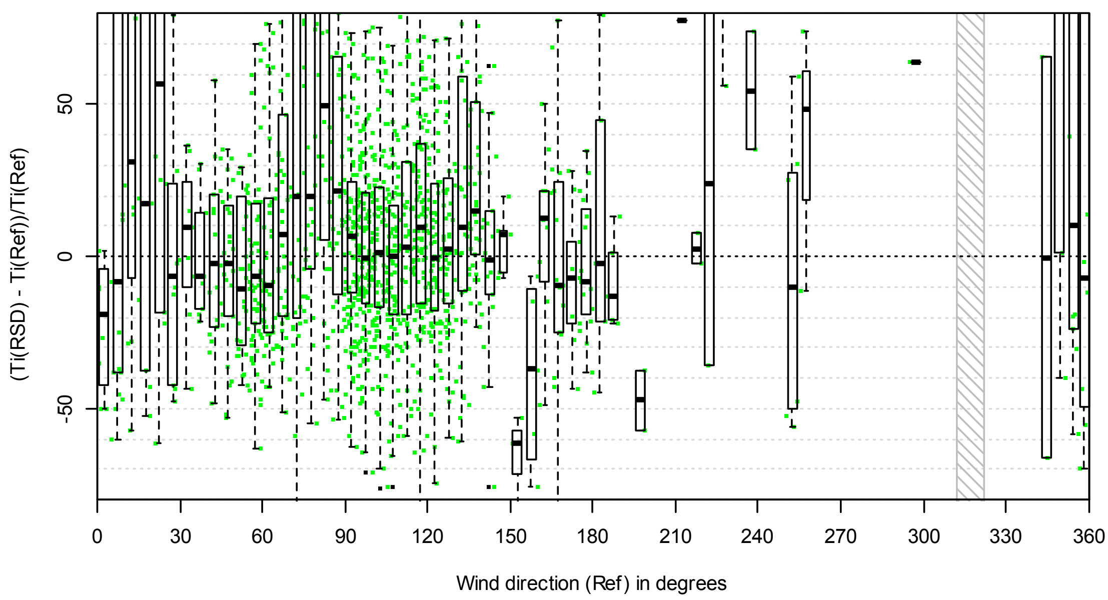
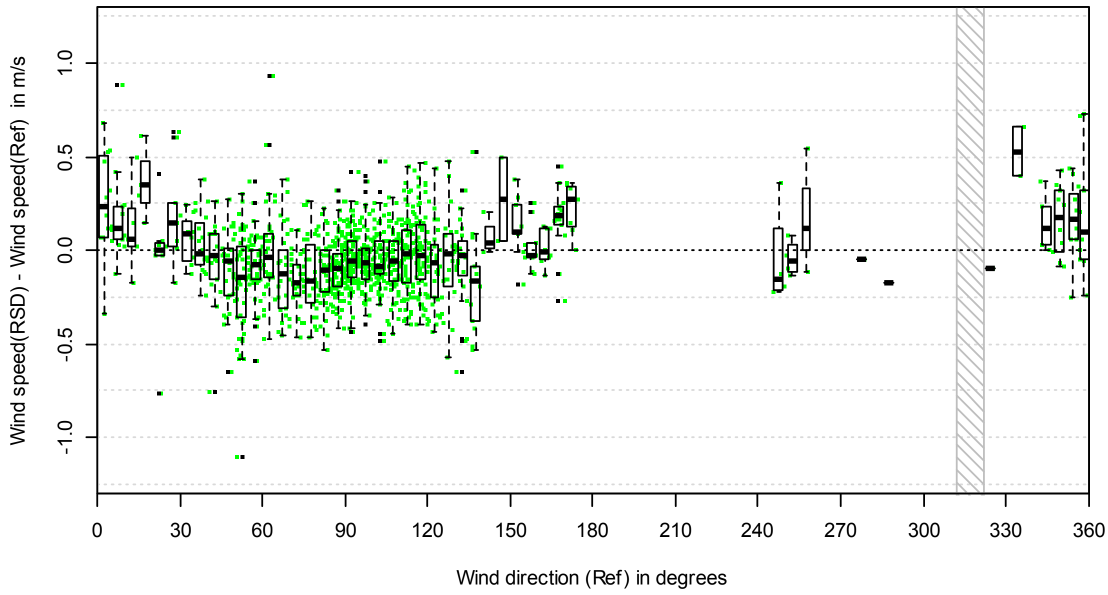


Fig. 44: Difference of turbulence intensity between RSD and reference data versus reference direction in degrees: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 80.1 m (V3) at the reference mast, 80.7 m at the RSD and the wind vane at 75.1 m (D2) height.

5.4.4 Distribution of ten minute mean wind at V4 (wind vane D3 at 55.1 m)



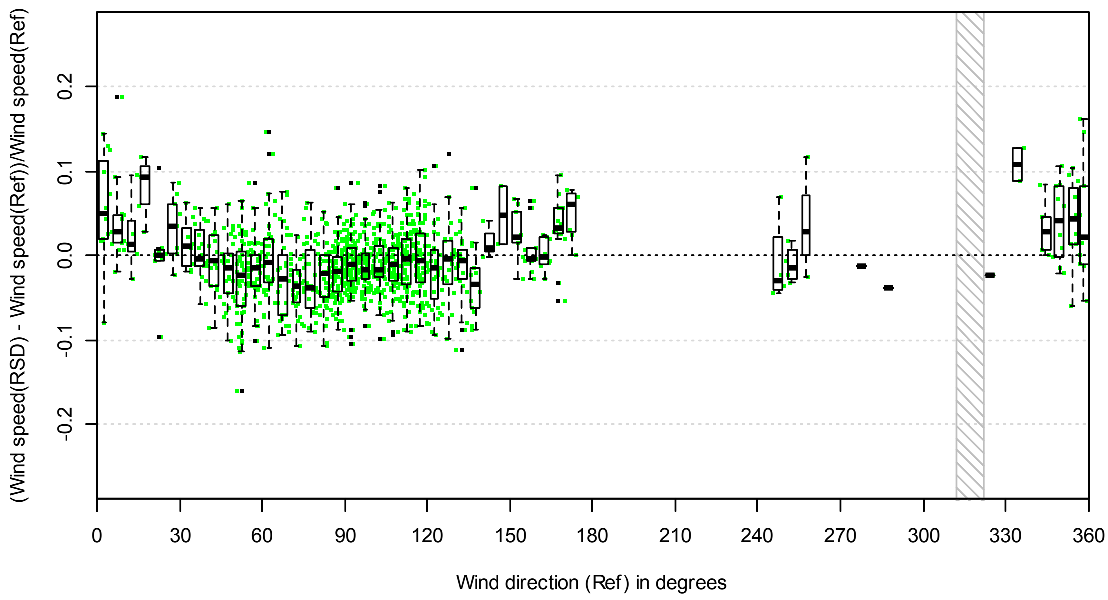
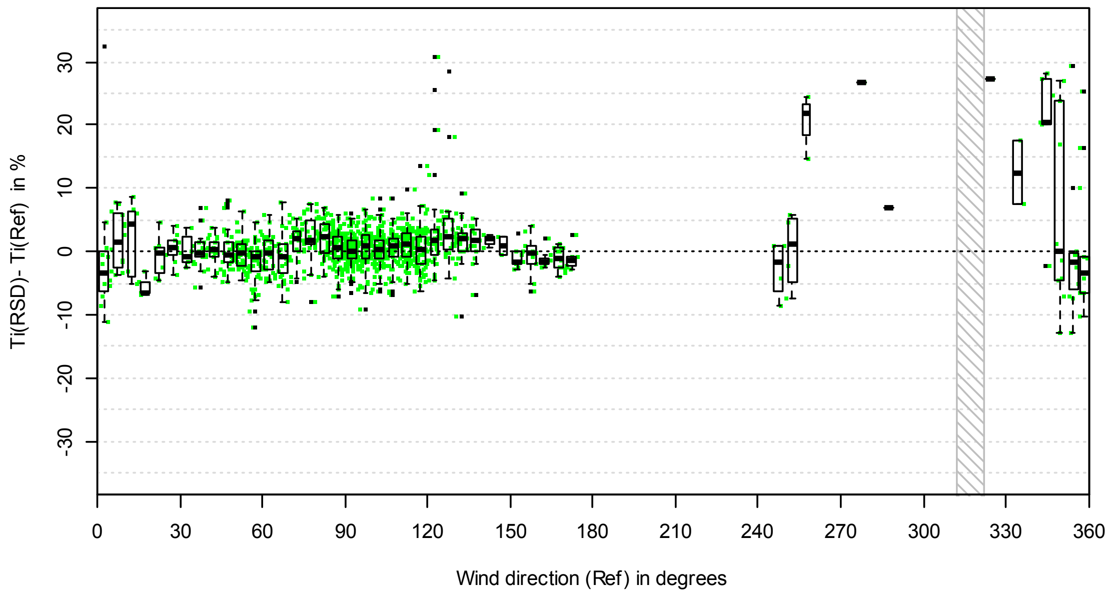


Fig. 45: Difference of wind speed between RSD and reference data versus reference direction in degrees at: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 60.1 m (V4) at the reference mast, 60.7 m at the RSD and the wind vane at 55.1 m (D3) height.



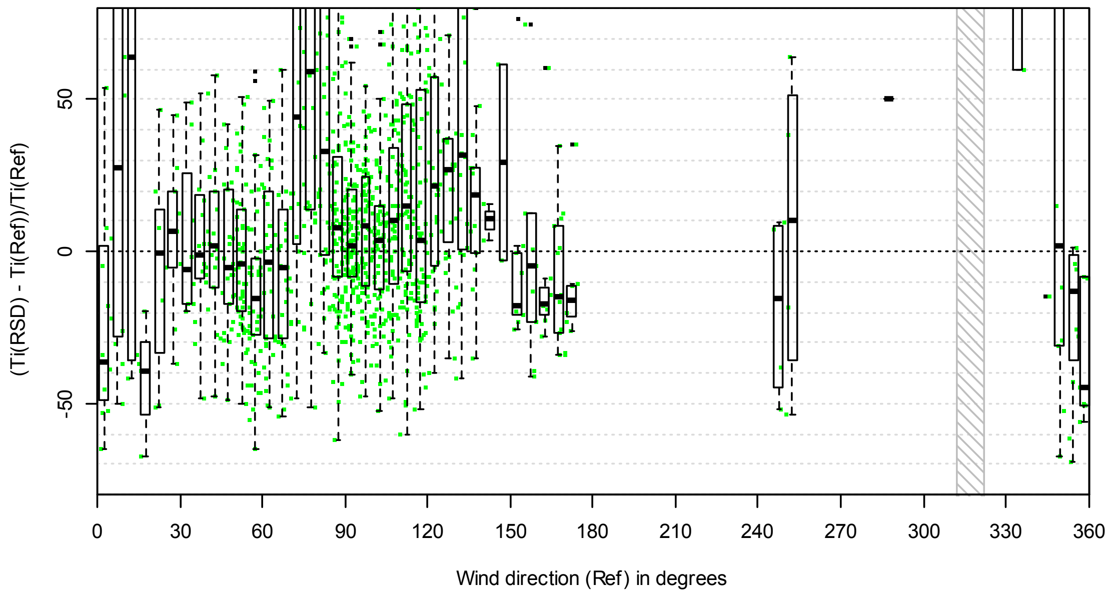


Fig. 46: Difference of turbulence intensity between RSD and reference data versus reference direction in degrees: (Upper) absolute difference; (Lower) relative difference. Boxes extend from the 25th to 75th percentile for each bin. Whiskers extend to the 5th and 95th percentile for each bin. Outliers are represented by small black points. Measurements at 60.1 m (V4) at the reference mast, 60.7 m at the RSD and the wind vane at 55.1 m (D3) height.

5.5 Acceptance criteria of the data

Within the verification process the remote sensing device needs to fulfil several acceptance criteria to proof its valid operation. The acceptance criteria are mainly based on the demands of [1] and [9] and on own investigations.

- Availability: For each height the RSD should acquire at least 80 % of the maximum possible number of valid 10-min measurement data sets (unfiltered) within the verification campaign.
- Valid data amount: 600 valid measurement data sets at each height after applying all relevant data filters to RSD and reference met mast (Ref).
- Completeness: 150 valid measurement data sets at each height for two wind speed bins (4 m/s – 8 m/s, 8 m/s – 16 m/s) after applying all relevant data filters to RSD and Ref.
- Wind speed deviation: At all heights the comparison of the 10-min data sets between RSD and Ref should not show higher values than 0.2 m/s for the 'absolute mean deviation'.
- Linear regression: For each height a linear regression based on the mean wind speed bins of RSD and Ref and forced through origin needs to have a slope within the range of 0.985 and 1.015.
- Correlation: For each height and based on the mean wind speed bins of RSD and Ref the coefficient of determination needs to have values of $R^2 > 0.996$.

5.5.1 Verification results of the data regarding the acceptance criteria

Based on the results obtained within this verification campaign and presented in this chapter the verified RSD defined in this report shows following performance regarding the acceptance criteria defined above:

Tab. 12: Summary of the acceptance criteria for the verification of the RSD for 105.7 m (V1):

Acceptance criteria	Requirement	Value	Passed / Failed
Availability	> 80 %	99.7%	Passed
Valid data sets	600	1465	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥4 m/s and <8 m/s	150	1408	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥8 m/s and <16 m/s	150	57	Failed
Absolute mean deviation between RSD and Ref	< 0.2 m/s	0.013 m/s	Passed
Slope (m) of the linear regression between RSD and Ref	0.985 ≤ m ≤ 1.015	1.0038	Passed
Coefficient of determination between RSD and Ref	$R^2 > 0.996$	1	Passed

Tab. 13: Summary of the acceptance criteria for the verification of the RSD for 100.7 m (V2):

Acceptance criteria	Requirement	Value	Passed / Failed
Availability	> 80 %	99.6 %	Passed
Valid data sets	600	1456	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥4 m/s and <8 m/s	150	1406	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥8 m/s and <16 m/s	150	50	Failed
Absolute mean deviation between RSD and Ref	< 0.2 m/s	0.007 m/s	Passed
Slope (m) of the linear regression between RSD and Ref	0.985 ≤ m ≤ 1.015	1.0012	Passed
Coefficient of determination between RSD and Ref	$R^2 > 0.996$	1	Passed

Tab. 14: Summary of the acceptance criteria for the verification of the RSD for 80.7 m (V3):

Acceptance criteria	Requirement	Value	Passed / Failed
Availability	> 80 %	100 %	Passed
Valid data sets	600	1400	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥4 m/s and <8 m/s	150	1374	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥8 m/s and <16 m/s	150	26	Failed
Absolute mean deviation between RSD and Ref	< 0.2 m/s	< 0.024 m/s	Passed
Slope (m) of the linear regression between RSD and Ref	0.985 ≤ m ≤ 1.015	1.0057	Passed
Coefficient of determination between RSD and Ref	$R^2 > 0.996$	1	Passed

Tab. 15: Summary of the acceptance criteria for the verification of the RSD for 60.7 m (V4):

Acceptance criteria	Requirement	Value	Passed / Failed
Availability	> 80 %	100 %	Passed
Valid data sets	600	1156	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥4 m/s and <8 m/s	150	1145	Passed
Valid data sets at U_{RSD} with U_{Ref} ≥8 m/s and <16 m/s	150	11	Failed
Absolute mean deviation between RSD and Ref	< 0.2 m/s	< 0.041 m/s	Passed
Slope (m) of the linear regression between RSD and Ref	0.985 ≤ m ≤ 1.015	0.9938	Passed
Coefficient of determination between RSD and Ref	$R^2 > 0.996$	1	Passed

The results for the verified heights at 105.7 m, 100.7 m 80.7 m and 60.7 m are in good compliance with the criteria for the coefficient of determination.
A numerical value of 1 for the coefficient of correlation is the result of rounding to the fourth decimal digit.

6 UNCERTAINTIES

The uncertainty of the wind speed measurements of the RSD is defined for each wind speed bin and for each height individually. It is assumed that all sources of uncertainty are uncorrelated/independent from each other. Therefore the total uncertainty of the measurement is calculated as the square root of the sum of the square of the single uncertainties that are relevant in the measurement/verification process:

$$Total = \sqrt[2]{Ref^2 + \overline{(U_{RSD} - U_{Ref})}^2 + \left(\frac{\sigma(U_{RSD})}{\sqrt{n}}\right)^2 + Mount^2 + Site^2}$$

where $Total$ = Total RSD uncertainty in % (k=1),

Ref = Reference sensor uncertainty in %,

$\overline{(\mathrm{U}_{\mathrm{RSD}} - \mathrm{U}_{\mathrm{Ref}})}$ = Mean deviation in %,

$\frac{\sigma(\mathrm{U}_{\mathrm{RSD}})}{\sqrt{\mathrm{n}}}$ = Precision of the RSD in %,

$Mount$ = Uncertainty caused by the RSD mounting in %,

$Site$ = Uncertainty caused by site effects in %.

The RSD mounting effects ($Mount$) are small as the inclination of the RSD was small.

The RSD is placed approximately 102 m beside the mast. This distance is close enough to allow a good correlation between mast and RSD. Considering also the flat terrain without any significant variation in terrain height within the relevant distance a low uncertainty for the site effects of 0.5 % for the upper heights has been chosen. For the lower measurement heights (81 m, 61 m) an influence of the nearby forests could be seen. As the sectors could not be excluded an uncertainty of 1 % resp. 1.5 % has been used for this heights.

The uncertainty contributions of the reference sensor are all stated with a coverage factor of one (k=1). According to ISO 17025 the total uncertainty of the RSD wind speed measurement is based on a coverage factor k=2 in order to reach a coverage of 95 %.

6.1 Uncertainties of the speed bins

Tab. 16: Results of the binned data comparison and uncertainty calculation with the total uncertainty (k=1, "Total") and the total uncertainty with a coverage factor of 2 (k=2, "Total*2") at 105.7 m.

Binned measurements					Bin uncertainties						
$\overline{U_{ref}}$	$\overline{U_{RSD}}$	n	$U_{RSD}\ range$	$\sigma(U_{RSD})$	$\frac{\sigma(U_{RSD})}{\sqrt{n}}$	$\overline{U_{RSD}-U_{ref}}$	Ref	$Mount$	$Site$	$Total$	$Total*2$
m s^{-1}	m s^{-1}	-	m s^{-1}	m s^{-1}	%R	%R	%R	%R	%R	%R	%R
4.027	4.091	187	3.76 - 5.36	0.217	0.394	1.586	4.251	0.5	0.5	4.581	9.163
4.491	4.472	246	3.82 - 5.08	0.252	0.357	-0.436	3.818	0.5	0.5	3.891	7.783
4.987	4.945	233	3.77 - 5.43	0.282	0.37	-0.841	3.446	0.5	0.5	3.601	7.201
5.508	5.505	189	3.83 - 6.34	0.319	0.421	-0.051	3.127	0.5	0.5	3.195	6.389
5.979	6.014	173	5.08 - 6.78	0.249	0.316	0.58	2.887	0.5	0.5	3.004	6.007
6.467	6.459	153	4.21 - 7.14	0.373	0.467	-0.116	2.676	0.5	0.5	2.764	5.529
6.988	7.051	121	5.97 - 7.8	0.309	0.402	0.906	2.484	0.5	0.5	2.721	5.441
7.492	7.587	81	6.91 - 8.18	0.243	0.361	1.264	2.324	0.5	0.5	2.716	5.432
7.96	8.011	39	7.27 - 8.89	0.291	0.585	0.642	2.193	0.5	0.5	2.412	4.823
8.505	8.569	18	8.27 - 8.89	0.199	0.552	0.758	2.06	0.5	0.5	2.318	4.637
9.003	8.985	18	8.3 - 9.59	0.339	0.886	-0.204	1.953	0.5	0.5	2.212	4.424
9.492	9.488	5	9.29 - 9.75	0.195	0.92	-0.042	1.859	0.5	0.5	-	-
9.785	9.76	2	9.73 - 9.79	0.042	0.307	-0.255	1.808	0.5	0.5	-	-

Tab. 17: Results of the binned data comparison and uncertainty calculation with the total uncertainty (k=1, "Total") and the total uncertainty with a coverage factor of 2 (k=2, "Total*2") at 100.7 m.

Binned measurements					Bin uncertainties						
$\overline{U_{ref}}$	$\overline{U_{RSD}}$	n	$U_{RSD}\ range$	$\sigma(U_{RSD})$	$\frac{\sigma(U_{RSD})}{\sqrt{n}}$	$\overline{U_{RSD}-U_{ref}}$	Ref	$Mount$	$Site$	$Total$	$Total*2$
m s^{-1}	m s^{-1}	-	m s^{-1}	m s^{-1}	%R	%R	%R	%R	%R	%R	%R
4.032	4.085	197	3.76 - 5.16	0.216	0.381	1.303	2.53	0.5	0.5	2.914	5.829
4.491	4.488	264	3.83 - 5.2	0.241	0.331	-0.063	2.282	0.5	0.5	2.36	4.721
4.997	4.965	226	4.17 - 5.7	0.253	0.337	-0.622	2.063	0.5	0.5	2.237	4.475
5.521	5.507	193	3.88 - 6.16	0.278	0.363	-0.258	1.879	0.5	0.5	1.995	3.989
5.994	6.02	173	5.27 - 6.72	0.258	0.327	0.425	1.742	0.5	0.5	1.889	3.779
6.477	6.461	141	5.51 - 7.43	0.295	0.384	-0.25	1.623	0.5	0.5	1.759	3.518
6.983	7.027	119	5.99 - 7.75	0.277	0.364	0.626	1.517	0.5	0.5	1.754	3.507
7.478	7.523	68	7.19 - 8.13	0.213	0.346	0.596	1.428	0.5	0.5	1.662	3.324
7.94	7.965	34	7.25 - 8.95	0.318	0.687	0.32	1.355	0.5	0.5	1.631	3.262
8.464	8.511	20	8.06 - 8.79	0.193	0.511	0.561	1.283	0.5	0.5	1.572	3.144
8.999	8.948	17	8.25 - 9.51	0.315	0.849	-0.562	1.219	0.5	0.5	1.665	3.33
9.5	9.423	3	9.32 - 9.54	0.111	0.672	-0.807	1.165	0.5	0.5	-	-
9.77	9.68	1	9.68 - 9.68	-	-	-0.921	1.139	0.5	0.5	-	-

Tab. 18: Results of the binned data comparison and uncertainty calculation with the total uncertainty (k=1, "Total") and the total uncertainty with a coverage factor of 2 (k=2, "Total*2") at 80.7 m.

Binned measurements					Bin uncertainties						
$\overline{U_{ref}}$	$\overline{U_{RSD}}$	n	$U_{RSD}\ range$	$\sigma(U_{RSD})$	$\frac{\sigma(U_{RSD})}{\sqrt{n}}$	$\overline{U_{RSD}-U_{ref}}$	Ref	$Mount$	$Site$	$Total$	$Total*2$
m s-1	m s-1	-	m s-1	m s-1	%R	%R	%R	%R	%R	%R	%R
4.023	4.062	271	3.76 - 4.63	0.185	0.279	0.979	2.535	0.5	1	2.909	5.819
4.497	4.497	308	3.95 - 5.06	0.221	0.28	-0.009	2.279	0.5	1	2.505	5.009
5	5.031	241	4.41 - 5.75	0.249	0.321	0.613	2.062	0.5	1	2.393	4.787
5.496	5.535	180	4.83 - 6.2	0.242	0.328	0.703	1.887	0.5	1	2.272	4.544
5.972	5.975	153	5.27 - 6.64	0.25	0.339	0.046	1.747	0.5	1	2.042	4.084
6.466	6.499	118	5.8 - 7.17	0.287	0.409	0.515	1.625	0.5	1	2.018	4.037
6.935	6.965	61	5.64 - 7.68	0.302	0.557	0.429	1.526	0.5	1	1.955	3.911
7.485	7.548	27	7.11 - 8.07	0.223	0.574	0.834	1.426	0.5	1	2.015	4.03
8.007	8.079	30	7.18 - 8.89	0.308	0.702	0.893	1.345	0.5	1	2.025	4.05
8.494	8.474	5	8.21 - 8.85	0.237	1.246	-0.235	1.279	0.5	1	-	-
8.892	8.694	5	8.34 - 9.3	0.413	2.078	-2.227	1.231	0.5	1	-	-
9.62	9.44	1	9.44 - 9.44	-	-	-1.871	1.154	0.5	1	-	-

Tab. 19: Results of the binned data comparison and uncertainty calculation with the total uncertainty (k=1, "Total") and the total uncertainty with a coverage factor of 2 (k=2, "Total*2") at 60.7 m.

Binned measurements					Bin uncertainties						
$\overline{U_{ref}}$	$\overline{U_{RSD}}$	n	$U_{RSD}\ range$	$\sigma(U_{RSD})$	$\frac{\sigma(U_{RSD})}{\sqrt{n}}$	$\overline{U_{RSD}-U_{ref}}$	Ref	$Mount$	$Site$	$Total$	$Total*2$
m s-1	m s-1	-	m s-1	m s-1	%R	%R	%R	%R	%R	%R	%R
4.028	4.013	287	3.76 - 4.61	0.18	0.264	-0.375	2.533	0.5	1.5	2.979	5.958
4.484	4.437	315	3.87 - 5.58	0.25	0.314	-1.052	2.285	0.5	1.5	2.946	5.892
5.004	4.957	181	4.3 - 5.88	0.262	0.389	-0.946	2.06	0.5	1.5	2.746	5.492
5.476	5.42	154	4.77 - 5.99	0.243	0.357	-1.024	1.893	0.5	1.5	2.648	5.295
5.97	5.91	97	5.22 - 6.54	0.275	0.468	-1.013	1.748	0.5	1.5	2.559	5.119
6.464	6.425	54	5.75 - 7.12	0.264	0.557	-0.61	1.626	0.5	1.5	2.361	4.722
6.964	6.921	31	5.72 - 7.27	0.286	0.737	-0.614	1.521	0.5	1.5	2.341	4.683
7.501	7.552	16	7.06 - 8.65	0.389	1.297	0.679	1.424	0.5	1.5	2.534	5.068
7.951	7.862	13	7.17 - 8.81	0.363	1.267	-1.128	1.353	0.5	1.5	2.638	5.276
8.527	8.47	4	8.24 - 9.03	0.377	2.212	-0.674	1.275	0.5	1.5	-	-
8.88	8.463	3	8.17 - 9.02	0.482	3.136	-4.692	1.232	0.5	1.5	-	-
9.37	9.25	1	9.25 - 9.25	-	-	-1.281	1.179	0.5	1.5	-	-

7 SUMMARY AND CONCLUSIONS

Congruent wind measurements with a remote sensing device anemometer (RSD) and cup anemometers have been carried out at a site close to Fimmerstad, Sweden. The aim of this measurement is to verify the RSD measurement against a well-known high quality standard (First Class cup anemometers with MEASNET calibration).

From the met mast (Ref) four measurement heights at 103.8 m, 100.9 m, 80.1 m and 60.1 m were available for wind speed comparisons. The verification measurement started on 05.09.2014 and ended on 20.09.2014 (approx. 15 days). The duration of the test period was long enough to successfully pass 3 of 4 data criteria. Because of a low wind speed situation during the measurement campaign not enough data sets could be sampled within the data interval for higher wind speeds. Nevertheless the results of the data gathered are considered as sufficient for the purpose of characterizing the performance of the AQ510 SoDAR (Serial no.: 003).

Between the heights of 40.7 m and 200.7 m above ground level (a. g. l.) 33 measurement heights have been configured at the RSD. The total system availability was between 97.6 % (60.7 m a. g. l.) and 94.2 % (105.7 m a. g. l.).

The measurements at 60.7 m a. g. l. and at 80.7 m a. g. l. are affected by forests in the northwest and southeast. Because omitting these sectors would have reduced the number of available data sets below a minimum quantity these sectors were not excluded but considered with a higher site effect uncertainty.

A data filtering has been applied to filter unrepresentative data sets resulting in data availabilities between 67.4 % (105.7 m a. g. l) and 53.1 % (60.7 m a. g. l.).

Several wind speed, wind direction and turbulence comparisons were carried out for each congruent measurement height. The wind speeds at all considered heights correlated very well, showing a good compliance to the cup wind speeds in terms of linear regression slopes and coefficient of determination values.

In summary, this verification campaign shows that the SODAR AQ510 003 is able to reproduce cup anemometer wind speeds at a highly accurate level at all speed bin means.

Based on the verification process described in this document the AQ510 003 has successfully passed the BBB Umwelttechnik GmbH (BBB) acceptance tests at all considered heights. Therefore this remote sensing device can be considered as verified for the use in wind and energy yield assessments in this and similar terrain types. Nevertheless the application in complex terrain needs to be designed and performed carefully considering guidelines (e. g. [10]) and the manufacturer manual defining the best practice for this application.

Care needs to be taken with respect to the use of RSD turbulence and extreme wind speed measurements, not treated in detail within this verification procedure but shown in recent studies to be different from classical cup anemometry measurements.

8 REFERENCES

[1] IEA Wind, "Ground-based vertically-profiling remote sensing for wind resource assessment," 03/2013.

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[3] IEC 61400-12-1, "Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines," 12/2005.

[4] Pedersen et al., "Wind Speed Measurement and Use of Cup Anemometry," 2003.

[5] MEASNET, "Cup Anemometer Calibration Procedure," 09/1997.

[6] AQSystem Stockholm AB, "Description of the Fimmerstadt met mast and surroundings," 19/03/2014.

[7] GL Garrad Hassan Deutschland GmbH, "Technical Conformance of AQS Met Mast and Test Site in Fimmerstadt, Sweden," 17/05/2013.

[8] R Core Team, *A Language and Environment for Statistical Computing*, Vienna: R Foundation for Statistical Computing, 2014.

[9] D. Kindler, "Best Practice Test and Verification Procedure for Wind LiDARs on the Hovsore Test Site. GLGH-D Report WT 6960/09 for EU-Project NORSEWInD," 2009.

[10] DNV, "Use of Remote Sensing for Wind Energy Assessments," Det Norske Veritas, 04/2011.

Appendix A: LIST OF ABBREVIATIONS

Abbreviation Acronym	Description
a. g. l.	Above ground level
BBB	BBB Umwelttechnik erneuerbare Energien GmbH
DIN	German Institute for Standardization, Deutsches Institut für Normung
DNV	Det Norske Veritas
EN	European Standard
IEC	International Electrotechnical Commission
IEA	International Energy Agency
k	Coverage factor
Met mast	Meteorological mast
n	Sample size
NAN	Not a number
OLS	Ordinary least square
Ref	Reference, here meteorological mast
RSD	Remote sensing device
U_{Ref}	Horizontal wind speed measured with the reference (in m/s)
U_{RSD}	Horizontal wind speed measured with the remote sensing device (in m/s)
UTC	Coordinated Universal Time

Appendix B: PANORAMA PHOTO FROM THE TEST SITE

Panorama photo taken at the base of the meteorological mast (17.06.2014, WGS 84: E 14.10991°, N 58.60566°)

Appendix C: CALIBRATION CERTIFICATES

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

akkreditiert durch die / *accredited by the*

Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Calibration mark 10060 D-K-15140-01-00 01/2013

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Vaisala FIN 00421 Helsinki
Typ *Type*	WAA252
Fabrikat/Serien-Nr. *Serial number*	Body: G15403 Cup: G154
Auftraggeber *Customer*	FDS Mätteknik AB 61291 Finspång, SWEDEN
Auftragsnummer *Order No.*	VT130141
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	07.01.2013

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
07.01.2013	Dipl. Phys. D. Westermann	Techniker Dirk Henninges

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10060 D-K-15140-01-00 01/2013

Kalibriergegenstand *Object*	Cup Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	257 cm²	
	diameter of mounting pipe [3]	27 mm	
	blockage ratio [4]	0.026 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen *Test conditions*	air temperature	20.4 °C	± 0.1 K
	air pressure	1026.9 hPa	± 0.3 hPa
	relative air humidity	41.2 %	± 2.0 %
Akkreditierung *Accreditation*	05/2011		
Anmerkungen *Remarks*	-		
Auswertesoftware *Software version*	7.0		

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling

Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Page

10060 D-K-15140-01-00 01/2013

Kalibrierergebnis:
Result:

File:	10060	
Test Item (1/s)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
37.778	4.153	0.05
56.380	6.065	0.05
74.180	7.900	0.05
92.431	9.740	0.05
111.651	11.698	0.05
130.344	13.658	0.05
149.237	15.619	0.05
138.869	14.586	0.05
121.026	12.701	0.05
101.516	10.727	0.05
83.388	8.801	0.05
64.891	6.929	0.05
47.910	5.178	0.05

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

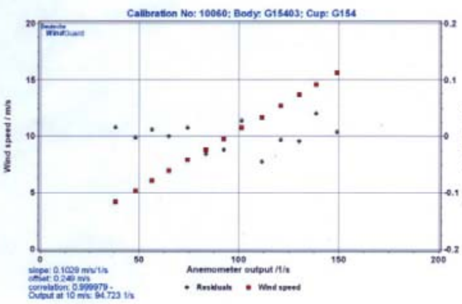
10060

1 Detailed Calibration Results

DKD calibration no.	10060
Serial no. 1	Body: G15403
Serial no. 2	Cup: G154
Date	07.01.2013
Air temperature	20.4 °C
Air pressure	1026.9 hPa
Humidity	41.2 %

Linear regression analysis

Slope	0.10295 (m/s)/(1/s) ±0.00020 (m/s)/(1/s)
Offset	0.2485 m/s ±0.020 m/s
St.err(Y)	0.020 m/s
Correlation coefficient	0.999979
Remarks	no



Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

10060

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up

Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

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Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

akkreditiert durch die / *accredited by the*

Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

D-K-15140-01-00

Deutschen Kalibrierdienst

Kalibrierschein
Calibration certificate

Calibration mark 1420651 / D-K-15140-01-00 / 02/2014

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.00.000
Fabrikat/Serien-Nr. *Serial number*	01142023
Auftraggeber *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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Kalibriergegenstand *Object*	Cup Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen *Test conditions*	air temperature	21.1 °C	± 0.1 K
	air pressure	994.1 hPa	± 0.3 hPa
	relative air humidity	37.0 %	± 2.0 %
Akkreditierung *Accreditation*	01/2013		
Anmerkungen *Remarks*	-		
Auswertesoftware *Software version*	7.60		

1) Querschnittsfläche der Auslassdüse des Windkanals
2) VereinfachteQuerschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
3) Durchmesser des Montagerohrs
4) Verhältnis von 2) zu 1)
5) Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

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Kalibrierergebnis:
Result:

File:	1420651	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.412	3.992	0.050
124.293	5.951	0.050
170.221	8.076	0.050
213.892	10.094	0.051
258.306	12.171	0.051
300.823	14.106	0.051
344.720	16.149	0.050
323.390	15.173	0.051
280.010	13.168	0.051
235.487	11.103	0.051
191.629	9.103	0.050
147.845	7.065	0.050
102.209	4.944	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Anhang
Annex

1420651

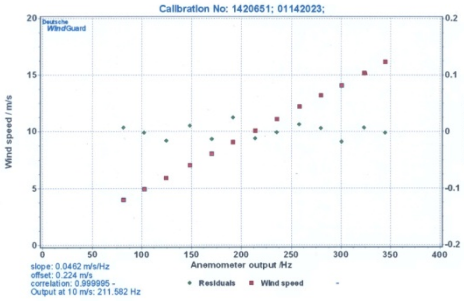
1 Detailed Calibration Results

DKD calibration no.	1420651
Body no.	01142023
Cup no.	
Date	01.02.2014
Air temperature	21.1 °C
Air pressure	994.1 hPa
Humidity	37.0 %

Linear regression analysis

Slope	0.04620 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
Offset	0.2239 m/s ±0.010 m/s
St.err(Y)	0.011 m/s
Correlation coefficient	0.999995

Remarks no



Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

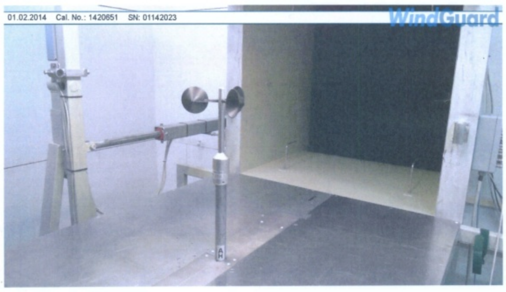
1420651

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Deutsche Akkreditierungsstelle GmbH

DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Calibration mark 1420650 D-K-15140-01-00 02/2014

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.00.000
Fabrikat/Serien-Nr. *Serial number*	01142024
Auftraggeber *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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Page

1420650 D-K-15140-01-00 02/2014

Kalibriergegenstand *Object*	Cup Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen *Test conditions*	air temperature	21.0 °C	± 0.1 K
	air pressure	993.9 hPa	± 0.3 hPa
	relative air humidity	37.0 %	± 2.0 %
Akkreditierung *Accreditation*	01/2013		
Anmerkungen *Remarks*	-		
Auswertesoftware *Software version*	7.60		

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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1420650
D-K-15140-01-00
02/2014

Kalibrierergebnis:
Result:

File:	1420650	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.991	3.993	0.050
124.154	5.955	0.050
170.156	8.076	0.050
213.543	10.096	0.051
258.676	12.171	0.051
300.875	14.109	0.051
344.960	16.152	0.050
324.195	15.180	0.051
280.281	13.164	0.051
235.713	11.104	0.051
192.101	9.101	0.051
147.932	7.063	0.050
101.987	4.949	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

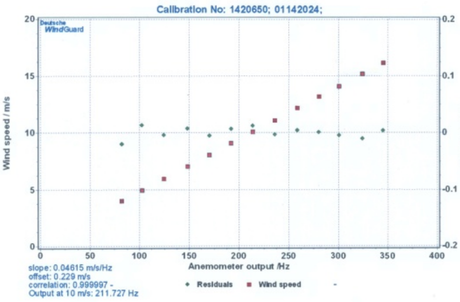
Deutsche WindGuard

Anhang
Annex

1420650

1 Detailed Calibration Results

DKD calibration no.	1420650
Body no.	01142024
Cup no.	
Date	01.02.2014
Air temperature	21.0 °C
Air pressure	993.9 hPa
Humidity	37.0 %
Linear regression analysis	
Slope	0.04615 (m/s)/(Hz) ±0.00003 (m/s)/(Hz)
Offset	0.2290 m/s ±0.007 m/s
St.err(Y)	0.004 m/s
Correlation coefficient	0.999997
Remarks	no



Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Deutsche WindGuard

Anhang
Annex

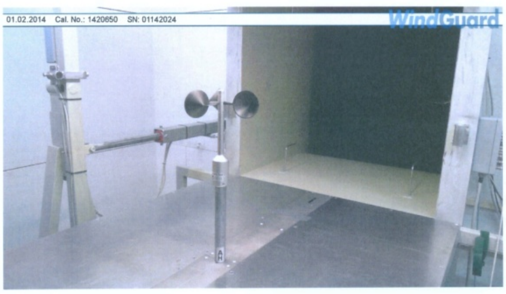
1420650

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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DAkkS
Deutsche Akkreditierungsstelle
D-K-15140-01-00

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Calibration mark

1420649
D-K-15140-01-00
02/2014

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.00.000
Fabrikat/Serien-Nr. *Serial number*	01142025
Auftraggeber *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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02/2014

Kalibriergegenstand
Object
Cup Anemometer

Kalibrierverfahren
Calibration procedure
IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12
ISO 3966 – Measurement of fluid in closed conduits – 2008-07

Ort der Kalibrierung
Place of calibration
Windtunnel of Deutsche WindGuard, Varel

Messbedingungen
Test Conditions

wind tunnel area [1]	10000 cm²	
anemometer frontal area [2]	230 cm²	
diameter of mounting pipe [3]	34 mm	
blockage ratio [4]	0.023 [-]	
blockage correction [5]	1.000 [-]	

Umgebungsbedingungen
Test conditions

air temperature	20.8 °C	± 0.1 K
air pressure	994.0 hPa	± 0.3 hPa
relative air humidity	37.2 %	± 2.0 %

Akkreditierung
Accreditation
01/2013

Anmerkungen
Remarks
-

Auswertesoftware
Software version
7.60

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Page

1420649
D-K-15140-01-00
02/2014

Kalibrierergebnis:
Result:

File:	1420649	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.492	3.995	0.050
123.723	5.957	0.050
169.766	8.082	0.050
213.781	10.097	0.051
258.433	12.179	0.051
300.835	14.109	0.051
345.198	16.152	0.050
324.041	15.184	0.051
279.645	13.165	0.051
234.959	11.104	0.051
191.881	9.102	0.050
147.642	7.062	0.050
101.886	4.953	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex
1420649

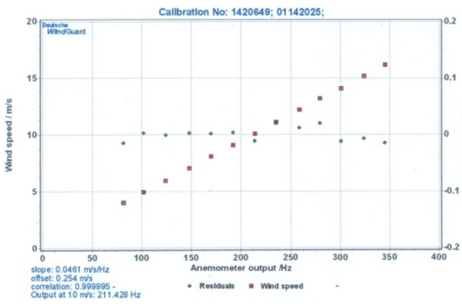
1 Detailed Calibration Results

DKD calibration no.	1420649
Body no.	01142025
Cup no.	
Date	01.02.2014
Air temperature	20.8 °C
Air pressure	994.0 hPa
Humidity	37.2 %

Linear regression analysis

Slope	0.04610 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
Offset	0.2541 m/s ±0.010 m/s
St.err(Y)	0.008 m/s
Correlation coefficient	0.999995

Remarks no



Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

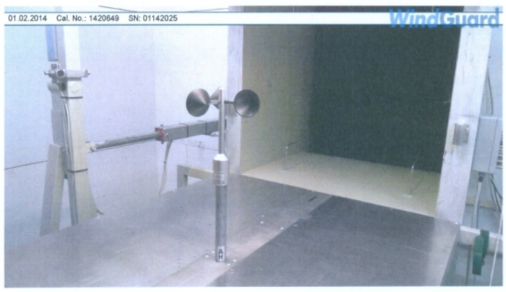
Anhang
Annex
1420649

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

Deutsche WindGuard
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Wind Tunnel Services GmbH, Varel

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Deutsche Akkreditierungsstelle GmbH

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

Kalibrierschein
Calibration certificate

Calibration mark 1420648 D-K-15140-01-00 02/2014

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.00.000
Fabrikat/Serien-Nr. *Serial number*	01142026
Auftraggeber *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit.
This calibration certificate may not be reproduced other than in full except with the permission of both the German Accreditation Body and the issuing laboratory. Calibration certificates without signature are not valid.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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Kalibriergegenstand *Object*	Cup Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen *Test conditions*	air temperature	20.6 °C	± 0.1 K
	air pressure	993.9 hPa	± 0.3 hPa
	relative air humidity	37.2 %	± 2.0 %
Akkreditierung *Accreditation*	01/2013		
Anmerkungen *Remarks*	-		
Auswertesoftware *Software version*	7.60		

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling

Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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Kalibrierergebnis:
Result:

File:	1420648	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.918	3.995	0.050
124.283	5.958	0.050
168.148	7.983	0.050
210.863	9.961	0.051
254.536	11.986	0.051
297.333	13.938	0.051
339.781	15.916	0.051
318.918	14.973	0.051
275.952	12.966	0.051
231.791	10.945	0.051
189.631	8.990	0.050
146.239	6.997	0.050
102.369	4.950	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

1420648

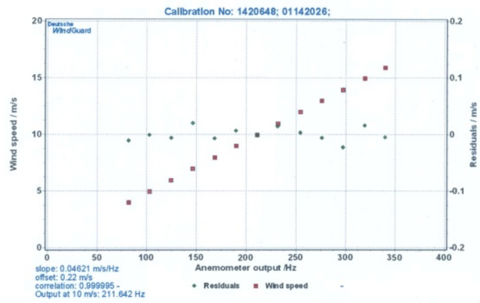
1 Detailed Calibration Results

DKD calibration no.	1420648
Body no.	01142026
Cup no.	
Date	01.02.2014
Air temperature	20.6 °C
Air pressure	993.9 hPa
Humidity	37.2 %

Deutsche WindGuard Wind Tunnel Services GmbH measnet

Linear regression analysis

Slope	0.04621 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
Offset	0.2201 m/s ±0.009 m/s
St.err(Y)	0.010 m/s
Correlation coefficient	0.999995
Remarks	no



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Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

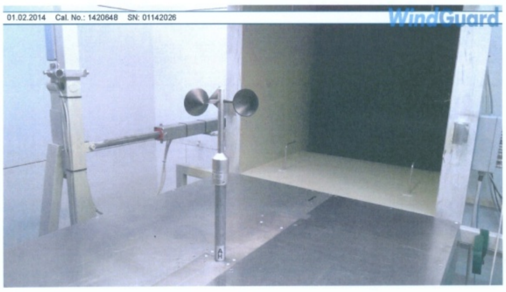
1420648

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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DAkkS Deutsche Akkreditierungsstelle D-K-15140-01-00

als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

1420647
D-K-15140-01-00
02/2014

Kalibrierschein
Calibration certificate

Calibration mark

Gegenstand / *Object*	Cup Anemometer
Hersteller / *Manufacturer*	Thies Clima D-37083 Göttingen
Typ / *Type*	4.3351.00.000
Fabrikat/Serien-Nr. / *Serial number*	01142027
Auftraggeber / *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer / *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines / *Number of pages of the certificate*	3
Datum der Kalibrierung / *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum / *Date*	Leiter des Kalibrierlaboratoriums / *Head of the calibration laboratory*	Bearbeiter / *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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Kalibriergegenstand / *Object*	Cup Anemometer		
Kalibrierverfahren / *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung / *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen / *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen / *Test conditions*	air temperature	20.5 °C	± 0.1 K
	air pressure	994.1 hPa	± 0.3 hPa
	relative air humidity	37.3 %	± 2.0 %
Akkreditierung / *Accreditation*	01/2013		
Anmerkungen / *Remarks*	-		
Auswertesoftware / *Software version*	7.60		

[1] Querschnittsfläche der Auslassdüse des Windkanals
[2] Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
[3] Durchmesser des Montagerohrs
[4] Verhältnis von 2) zu 1)
[5] Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

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02/2014

Kalibrierergebnis:
Result:

File:	1420647	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.727	3.996	0.050
123.945	5.956	0.050
170.024	8.080	0.051
213.557	10.097	0.051
258.229	12.175	0.051
300.431	14.111	0.051
345.058	16.153	0.050
323.873	15.183	0.051
280.269	13.170	0.051
234.993	11.102	0.051
192.464	9.103	0.051
147.997	7.074	0.050
101.902	4.959	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

Anhang
Annex

1420647

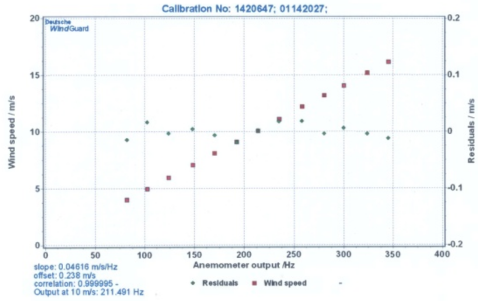
1 Detailed Calibration Results

DKD calibration no.	1420647
Body no.	01142027
Cup no.	
Date	01.02.2014
Air temperature	20.5 °C
Air pressure	994.1 hPa
Humidity	37.3 %

Linear regression analysis

Slope	0.04616 (m/s)/(Hz) ±0.00004 (m/s)/(Hz)
Offset	0.2383 m/s ±0.010 m/s
St.err(Y)	0.009 m/s
Correlation coefficient	0.999995

Remarks no



Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

Anhang
Annex

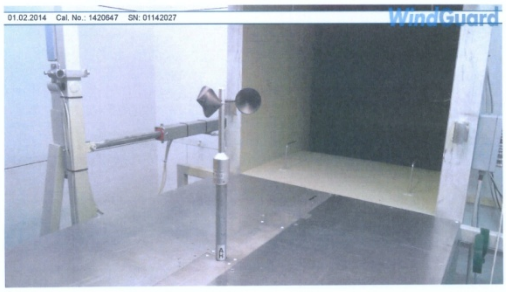
1420647

2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

Deutsche WindGuard
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als Kalibrierlaboratorium im / *as calibration laboratory in the*

Deutschen Kalibrierdienst DKD

Kalibrierschein
Calibration certificate

Calibration mark 1420646 D-K-15140-01-00 02/2014

Gegenstand *Object*	Cup Anemometer
Hersteller *Manufacturer*	Thies Clima D-37083 Göttingen
Typ *Type*	4.3351.00.000
Fabrikat/Serien-Nr. *Serial number*	01142028
Auftraggeber *Customer*	Ammonit Measurement GmbH D-10997 Berlin
Auftragsnummer *Order No.*	VT140181
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	3
Datum der Kalibrierung *Date of calibration*	01.02.2014

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.
This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Datum *Date*	Leiter des Kalibrierlaboratoriums *Head of the calibration laboratory*	Bearbeiter *Person in charge*
01.02.2014	D. Westermann Dipl. Phys. D. Westermann	C. Ahrens Techniker Christian Ahrens

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Kalibriergegenstand *Object*	Cup Anemometer		
Kalibrierverfahren *Calibration procedure*	IEC 61400-12-1 – Power performance measurements of electricity producing wind turbines – 2005-12 ISO 3966 – Measurement of fluid in closed conduits – 2008-07		
Ort der Kalibrierung *Place of calibration*	Windtunnel of Deutsche WindGuard, Varel		
Messbedingungen *Test Conditions*	wind tunnel area [1]	10000 cm²	
	anemometer frontal area [2]	230 cm²	
	diameter of mounting pipe [3]	34 mm	
	blockage ratio [4]	0.023 [-]	
	blockage correction [5]	1.000 [-]	
Umgebungsbedingungen *Test conditions*	air temperature	20.2 °C	± 0.1 K
	air pressure	994.4 hPa	± 0.3 hPa
	relative air humidity	37.5 %	± 2.0 %
Akkreditierung *Accreditation*	01/2013		
Anmerkungen *Remarks*	-		
Auswertesoftware *Software version*	7.60		

1) Querschnittsfläche der Auslassdüse des Windkanals
2) Vereinfachte Querschnittsfläche (Schattenwurf) des Prüflings inkl. Montagerohr
3) Durchmesser des Montagerohrs
4) Verhältnis von 2) zu 1)
5) Korrekturfaktor durch die Verdrängung der Strömung durch den Prüfling
Anmerkung: Aufgrund der speziellen Konstruktion der Messstrecke ist keine Korrektur nötig.
Remark: Due to the special construction of the test section no blockage correction is necessary

Dieser Kalibrierschein wurde elektronisch erzeugt
This calibration certificate has been generated electronically

Deutsche WindGuard
Wind Tunnel Services GmbH, Varel

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1420646
D-K-15140-01-00
02/2014

Kalibrierergebnis:
Result:

File:	1420646	
Test Item (Hz)	Tunnel Speed (m/s)	Uncertainty (k=2) (m/s)
81.500	4.000	0.050
124.061	5.960	0.050
168.192	7.992	0.050
210.896	9.965	0.051
254.828	11.990	0.051
296.918	13.937	0.051
340.428	15.920	0.051
319.506	14.976	0.051
275.775	12.964	0.051
231.699	10.948	0.051
189.013	8.986	0.050
146.059	6.999	0.050
101.470	4.955	0.050

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k=2 ergibt. Sie wurde gemäß DAkkS-DKD-3 ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Wertintervall.

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichnerin der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen.

The expanded uncertainty assigned to the measurement results is obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with DAkkS-DKD-3. The value of the measurand lies within the assigned range of values with a probability of 95%.

The DAkkS is signatory to the multilateral agree-ments of the European co-operation for Accredita-tion (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.

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1 Detailed Calibration Results

DKD calibration no.	1420646
Body no.	01142028
Cup no.	
Date	01.02.2014
Air temperature	20.2 °C
Air pressure	994.4 hPa
Humidity	37.5 %
Linear regression analysis	
Slope	0.04603 (m/s)/(Hz) ±0.00005 (m/s)/(Hz)
Offset	0.2649 m/s ±0.011 m/s
St.err(Y)	0.012 m/s
Correlation coefficient	0.999993
Remarks	no

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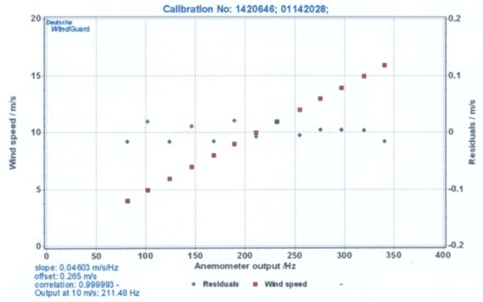

Deutsche WindGuard Wind Tunnel Services is accredited by MEASNET and by the Deutsche Akkreditierungsdienst – DAkkS (German Accreditation Service). Registration: D-K-15140-01-00

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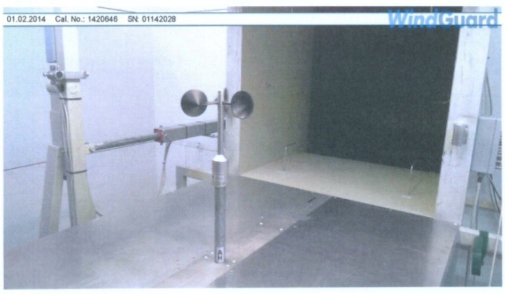
2 Instrumentation

Pos.	Sensor	Manufa.	Type	Range
1	Pitot static tube	Airflow	NPL 8 mm	-
2	Pitot static tube	Airflow	NPL 8 mm	-
3	Pitot static tube	Airflow	NPL 8 mm	-
4	Pitot static tube	Airflow	NPL 8 mm	-
5	Pressure transducer	Setra	C 239	250 Pa
6	Pressure transducer	Setra	C 239	250 Pa
7	Pressure transducer	Setra	C 239	250 Pa
8	Pressure transducer	Setra	C 239	250 Pa
9	El. Barometer	Vaisala	3.11.57.10.000	800hPa -1200 hPa
10	El. Thermometer	Galltec	KPK 1/6-ME	10° C - 40° C
11	El. Humidity sensor	Galltec	KPK 1/6-ME	0-100 %
12	Wind tunnel control	-	-	-
13	CAN-BUS / PC	esd	24 x 16 bit	

Table 1 Description of the data acquisition system
Remark: Last Re-accreditation see page 2

3 Photo of the calibration set-up



Calibration set-up of the anemometer calibration in the wind tunnel of Deutsche WindGuard, Varel. The anemometer and orientation shown may differ from the calibrated one. Remark: The proportion of the set-up is not true to scale due to imaging geometry.

4 Deviation to IEC procedure

The calibration procedure is in all aspects in accordance with the IEC 61400-12-1 Procedure

5 References

[1] D. Westermann, 2009 – Verfahrensanweisung DKD-Kalibrierung von Windgeschwindigkeitssensoren
[2] IEC 61400-12-1 12/2005 – Power performance measurements of electricity producing wind turbines
[3] ISO 3966 2008 – Measurement of fluid flow in closed conduits

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