Calibration Test of Sodar PA-XS

Serial No.: 597

Site: Georgsfeld,(Germany)

Contracted by

REMTECH
2 et 4 avenue de l'Europe
78140 Vélizy Villacoublay
France

Deutsche WindGuard Consulting GmbH
Oldenburger Straße 65
26316 Varel
Germany

Project No.: VC17301
Report No.: RSV18014.A1
Report Date: 2018-06-14

Calibration Test of Sodar PA-XS

Site: Georgsfeld, (Germany)

Customer:	REMTECH 2 et 4 avenue de l'Europe 78140 Vélizy Villacoublay France
Customer Contact:	Rémy Tasso
Contractor:	Deutsche WindGuard Consulting GmbH Oldenburger Straße 65 26316 Varel Germany Telephone: +49 4451 95 15 0 Fax: +49 4451 95 15 29 E-Mail: info@windguard.de
Project No.:	VC17301
Report No.:	RSV18014.A1
Date of Report:	2018-06-14
Author:	Dipl.-Ing. (FH) Ailt-Wiard Janssen
Approved by:	Dipl. Umweltwiss., Kathrin Martin

Deutsche WindGuard
Consulting GmbH
Oldenburger Straße 65
D-26316 Varel
Tel.: 04451 / 95 15 - 0 · Fax: 95 15 - 29

Revision History

Revision No.	Date	Status	Amendment
A0	2018-04-16	Final report	---
A1	2018-06-16	Final report	Corrected some spelling errors

Note: The last revision replaces all previous versions of the report.

Contents

Disclaimer:

We hereby state, that the results in this report are based upon generally acknowledged and state-of-the-art methods and have been neutrally conducted to the best of our knowledge and belief. No guarantee, however, is given and no responsibility is accepted by Deutsche WindGuard Consulting GmbH for the correctness of the derived results. The work presented in this report complies with the present day valid standards and guidelines and the corresponding quality management system of Deutsche WindGuard. Any partial duplication of this report is allowed only with written permission of Deutsche WindGuard Consulting GmbH. The results of the following report refer to the investigated test object only.

This report covers 88 pages.

1 Introduction

The PA-XS sodar is a sodar system (sodar=sound detection and ranging) for wind measurements in the lower atmosphere. The device provided by the French company Remtech, designed with consideration for the needs of the wind energy industry. This report describes a test of the accuracy of the RSD (Remote Sensing Device) with the serial number 597 against conventional wind measurements with mast mounted cup anemometers and conventional wind vanes.

The calibration describes the accuracy of the measurements of the RSD for the environmental conditions present at the test site during the test period. The environmental conditions present at an application of the RSD may deviate from the conditions present at the Calibration Test.

The reported Calibration Test follows the latest requirements as developed in the frame of the ongoing revision of the standard IEC 61400-12-1 [2]. The test took place at a special test station for remote wind sensing devices in Eastern Friesland, where a 135 m high met mast is available.

This report covers 88 pages.

2 Measurement Site and Met Mast

The measurement is located near the village Georgsfeld, approximately 5 km north-west of Aurich, in the region Eastern Frisia, which is in the north west of the German state of Lower Saxony. The distance to the North Sea is approximately 20 km.

The area around the met mast position is characterised by flat terrain. The terrain height at the met mast location is about 6 m above sea level. The best fit of a plane to the terrain up to 5km distance going through the bottom of the mast has no significant slope. The maximum deviation of the terrain to this plane is 11 m.

The landscape is characterised by farmland with closed appearance. The land development in the environment mainly consists of small villages, with tree rows along roads and field borders. Noteworthy are the town of Aurich (40 000 inhabitants) 5 km to the South East and a forest 1 km to the North West. In a distance 70 m to the mast an earth dike with low trees runs from South West to North East.

A map of the measurement site is given Figure 2.1. Photos of the met mast and a panoramic view of the site are shown in Figure 2.2 and Figure 2.3.

Figure 2.1: Map of the measurement site. The wind turbines E-126 limit the measurement sector. The met mast and is marked by a black square with the black dots marking the anchor points of the guy wires. The RSD was located on the field northwest of the met mast (circle).

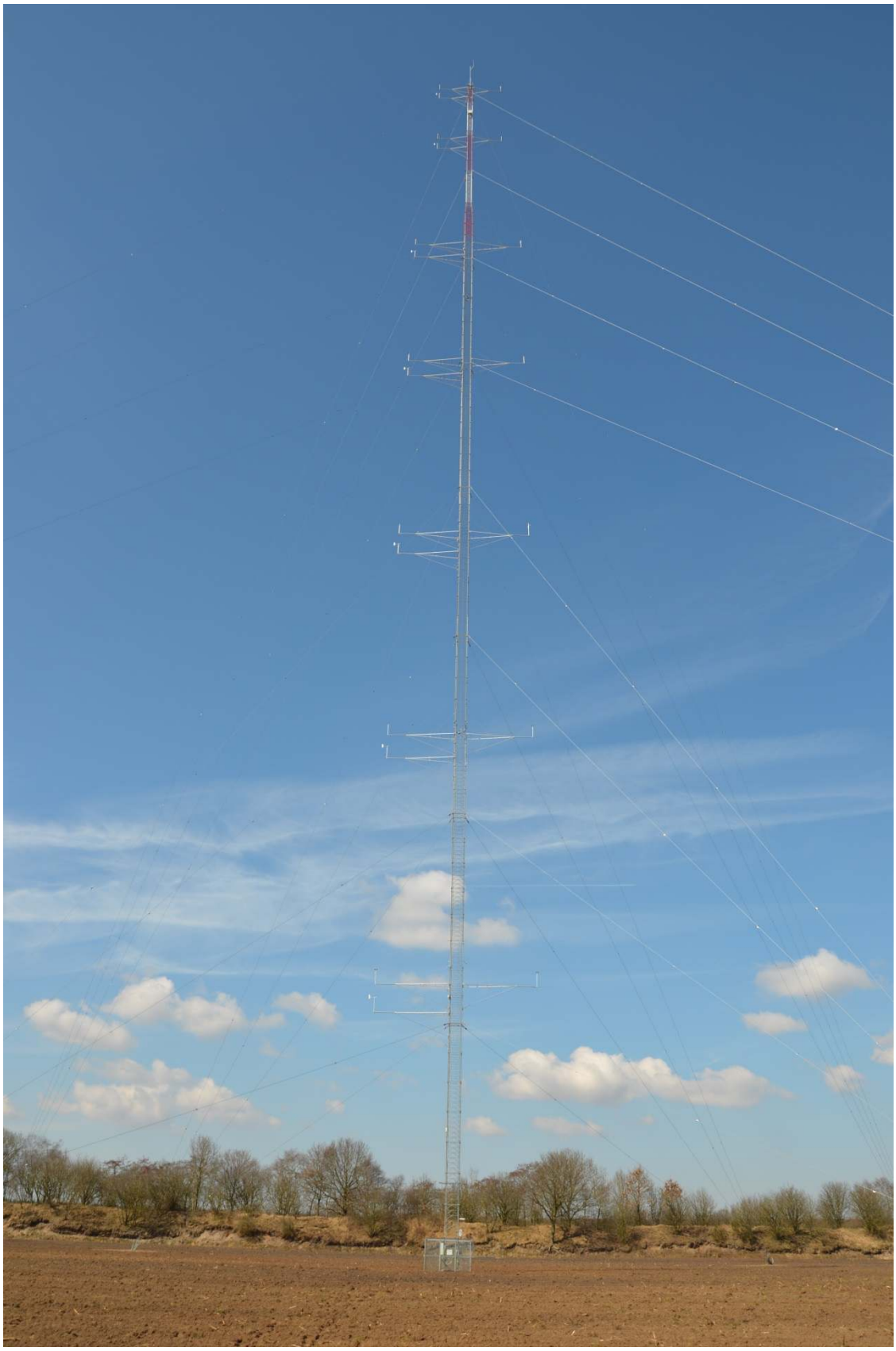

Figure 2.2: Photo of the 135 m high met mast near Georgsfeld, looking in direction southwest.

N=0° E=90°

E=90° S=180°

Figure 2.3: Panoramic view of the measurement site taken 13 m from the bottom of the met mast (continued).

S=180° W=270°

W=270° N=360°

Figure 2.3: Panoramic view of the measurement site taken 13 m from the bottom of the met mast (end).

During the measurement, the RSD was installed 242 m west of the met mast (Figure 2.4).

The met mast is positioned about 357 m west of a test wind turbine. The test wind turbine and other neighbouring turbines influence the airflow at the mast at easterly and south westerly wind directions. The coordinates and the resulting wake effects calculated according IEC 61400-12-1 for power performance measurements [1] can be seen in detail in Table 2.1. From all these wakes, an undisturbed and applicable sector of 253° to 29° remains for testing the RSD. The measurement sector must be reduced further for some reference sensors due to mast effects (see Table 2.2). The RSD was aligned to 70°. The bearing was taken over an edge of the frame of the RSD.

Figure 2.4: The RSD under test installed next to the met tower.

The met mast is equipped with several cup and ultrasonic anemometers as well as wind vanes in different heights above ground. The airflow at the positions of the anemometers and vanes is significantly influenced by flow disturbance caused by the mast and neighbouring sensors (blockage effects, flow acceleration effects). The least influence occurs at the cup anemometer of type Thies First Class Advanced which is mounted at 135 m height above ground at the top of the met mast. An individual wind direction depending correction has been applied to the wind speed measurements of the cup and ultrasonic anemometers which are mounted on side booms to the mast (all mounting heights except 135 m). Those correction functions have been determined empirically. The cup anemometers are of class 0.9A according to reference [1], [3]. The cup and also the ultrasonic anemometers have been calibrated in a wind tunnel according to DKD and MEASNET [4]. One of the calibration wind tunnels of DWG is applied by the German authority for controlling units, Physikalisch-Technische Bundesanstalt (PTB), for defining the unit m/s in airflow measurements. A more accurate tracing back of the anemometer measurements is currently not possible. The ultrasonic anemometers were calibrated for different horizontal and vertical orientations. The wind measurements with the mast follow the requirements of IEC 61400-12-1 [1].

A list of the undertaken comparisons of sensors of the met mast and measurements of the RSD are given in Table 2.2. From the table, the disturbed sectors caused by the mast and the neighbouring turbines and the chosen evaluation sectors can be seen. The positions of the laser beams in dependence of the measuring height have been taken into account for the calculation of the disturbed sectors. Table 2.3 shows the specifications of the sensors mounted at the met mast.

Object	Position		Rotor diameter D	Distance from met mast	Direction from met mast	Met Mast in Wake	
	X	Y				from	to
	[m]	[m]	[m]	[m]	[deg]	[deg]	[deg]
Met mast	2595735	5931491	---	---	---	---	---
RSD	2595515	5931594	---	242	293	---	---
E-126 E2	2596091	5931472	127	356.5	93	58	128
E-126-1	2595429	5930971	127	603.4	210	183	237
E-126-2	2594786	5930479	127	1387.4	223	205	242

Table 2.1: Position of met mast, RSD and neighbouring turbines. All coordinates are given in Gauß-Krüger coordinates (Bessel-Ellipsoid).

RSD	met mast sensor					RSD Complete sector		evaluation sector	
Selected Height	signal	meas-urement height [1]	boom ori-ent.	in mast wake					
				from	to	From	To	from	to
[m]	[-]	[m]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
135	V1	135.0	cen-tral	-	-	242 135	58 164	242 135	29 164
120	V3	120.4 100.3	225	29	62	242 134	58 165	329 134 242	29 165 310
100	V5	100.3 82.2	225	30	62	242 133	58 166	242 133	30 166
80	V6	82.2 60.4	225	31	64	242 132	58 166	242 132	31 166
60	V8	60.4 40.3	225	31	64	242 131	58 167	242 131	31 167
40	V9	60.4 40.3	225	31	64	242 130	58 168	242 130	31 168
140	Dir1	129	225	29	54	242 135	58 164	242 135	29 164
120	Dir2	118.3	225	29	62	242 134	58 165	329 134 242	29 165 310
100	Dir3	98.2	225	30	62	242 133	58 166	242 133	30 166
80	Dir4	80.1	225	31	64	242 132	58 166	242 132	31 166
60	Dir5	58.2	225	31	64	242 131	58 167	242 131	31 167
40	Dir5	38.2	225	31	64	242 130	58 168	242 130	31 168

Table 2.2: List of the undertaken comparisons, sensors/channels of met mast and RSD measurements with measuring heights, orientation of sensor mounting booms and sector restrictions due to wake effects of the mast and neighbouring turbines, as well as effective evaluation sectors. For some measuring heights of the RSD, no corresponding sensor at the mast exists.

[1] *interpolated between upper and lower height to RSD level (except for top height of RSD)*

Sensor	Height	Type	Serial	Calibration
Cup Anemometer v1	135.0 m	Thies First Class Adv.	6130299	1712227
Cup Anemometer v2	131.0 m	Thies First Class Adv.	6130298	1712226
Cup Anemometer v3	120.4 m	Thies First Class Adv.	6130297	1712224
Cup Anemometer v5	100.3 m	Thies First Class Adv.	6130295	1712222
Cup Anemometer v6	82.2 m	Thies First Class Adv.	6130294	1712220
Cup Anemometer v8	60.4 m	Thies First Class Adv.	6130292	1712221
Cup Anemometer v9	40.3 m	Thies First Class Adv.	6130291	1712223
Wind vane dir1	129.0 m	Thies First Class 4.3150.00.140	6130155	1721778
Wind vane dir2	118.3 m	Thies First Class 4.3150.00.140	6130156	1721779
Wind vane dir3	98.2 m	Thies First Class 4.3150.00.140	6130157	1721773
Wind vane dir4	80.1 m	Thies First Class 4.3150.00.140	6130158	1721774
Wind vane dir5	58.2 m	Thies First Class 4.3150.00.140	6130161	1721777
Wind vane dir6	38.2 m	Thies First Class 4.3150.00.140	6130159	1721775
Temperature T1/H1	130.6 m	Galtec + Mela KRC3/6.ME	84231	IK16_090
Temperature T4/H2	18.3 m	Galtec + Mela KRC3/6.ME	84232	IK16_091

Table 2.3 Sensor specification list of mast mounted sensors which were used for calibration.

3 Set-Up of the RSD, Data Collection and Data Processing

3.1 Set-Up of the RSD

The evaluated measurement period was from 2017-09-20 to 2017-11-17. The RSD was supplied by solar panels in the measurement period. The basic information and key settings of the RSD are shown in the following table. The settings have not been changed in the measurement period.

Evaluated measurement period	2017-09-20 to 2017-11-17
RSD model	PA-XS
Unit serial number	597
Beam angle from vertical	22°
Selected measurement heights	40 m, 60 m, 80 m, 100 m, 120 m, 130 m, 135 m
North orientation during test	70°
Power supply	Solar
Firmware	V09.064

Table 3.1 Basic information and key settings of the tested RSD

The vertical and horizontal alignment of the RSD was adjusted by staff member of DWG at the start of the measurement. The horizontality was adjusted with the use of a water level. The horizontal orientation was controlled by a compass over the outer edge of the sodar. The horizontal orientation was 70°. The alignment did not change during the course of the measurements.

The RSD and the data acquisition system of the met mast have been synchronised to UTC time at the beginning of the campaign. During the measurement period, the time was synchronised by GPS.

3.2 Data Collection

The RSD stores data files in ASCII/text format converted into columns instead of data blocks thanks to the conversion software SodarWinPro provided by Remtech.

3.3 Data Processing

3.3.1 Extrapolation of Horizontal Wind Speed Component and its Standard Deviation as Measured by Anemometer

The RSD allows measurement height selection in integer meter values user's selectable steps. During this experiment 20 m layers was chosen. To evaluate the horizontal wind speed of same height levels the wind speeds of cup anemometers have been interpolated.

For this, a power law has been adjusted to the measurements of the horizontal wind speed component of cup anemometer for adjacent sensors (e.g. 135 m and 120.4 m) measurement height within each 10-minute period:

$$\alpha_v = \frac{\ln\left(\frac{v_{Anemometer,h_1}}{v_{Anemometer,h_2}}\right)}{\ln\left(\frac{h_1}{h_2}\right)} \quad (1)$$

$$v_{Anemometer,interpolated} = v_{Anemometer,h_1}\left(\frac{h_{interpolation}}{h_1}\right)^{\alpha_v}$$

where

α_v:	power law exponent in terms of the horizontal wind speed component
h_1:	measurement height of anemometer below height of reference
h_2:	measurement height of anemometer above height of reference
$h_{interpolated}$	interpolation height
$v_{Anemometer,h_1}$:	measurement of horizontal wind speed component of anemometer at height h_1
$v_{Anemometer,h_2}$:	measurement of horizontal wind speed component of anemometer at height h_2
$v_{Anemometer,interpolated}$:	interpolated wind speed

3.3.2 Correction of Wind Speeds Measured by Boom Mounted Anemometers

The anemometers on the mast mounted below the mast top are influenced by the flow blockage effects and flow acceleration effects caused by the mast. These mast effects on the anemometer measurements have been corrected by empirically determined corrections.

3.3.3 Wind Shear

A power law has been adjusted to the measurements of the horizontal wind speed component of the RSD at two measurement heights as close to a pair of successive measurement heights at the met mast within each 10- minute period (see eq. (1)). The wind shear exponents determined from the measurements of the RSD have been compared to the wind shear exponents determined from the mast measurements.

3.3.4 Wind Direction

The wind directions measured by the RSD as average of 10-minute periods have been compared directly to the measurements with the vanes at the nearest measurement heights of the mast. Small deviations in the measurement heights of the RSD and the heights of the reference sensors on the mast have been ignored.

3.4 Data Filtering

The following data filtering has been applied for the comparison of the measurements of the RSD and the mast based sensors:

- Based on the intercomparison results the following condition has been applied to the full set of data produced by the RSD: (Wind-speed of RSD<6 | (VAL1>=300 | VAL2>=300)). In other words for wind speeds greater than 6 m/s the data are valid if one of the tilted beams shows at least 300 validations (all layers together).
- Only wind directions, where the RSD and the reference sensor are exposed to free wind conditions (no wake effects), have been considered, i.e. the measurement sector according to Table 2.2 has been applied.
- Only wind speeds above 4 m/s as measured by the reference anemometer have been considered for the following reasons:
    - The wind tunnel calibration of the cup anemometer has been performed in the wind speed range 4-16 m/s according to MEASNET [4]. Despite the limitation of the wind tunnel calibrations to 16 m/s, the wind speed was not limited for testing the RSD in order to gain indications for the accuracy at higher wind speeds.
    - At low wind speeds, the cup anemometer measurements are linked to higher uncertainties.
    - Lower wind speeds are less relevant as hardly any energy is produced by wind turbines below 4 m/s.

It is noted that the derived results are valid only for these filters. Thus, the evaluated accuracy of the RSD can be expected in a later application only if the above flag filter of the RSD is applied.

4 Results of Calibration Test

4.1 Accuracy of the RSD in Terms of Availability

A total amount of 4666 10-minute periods was covered by the evaluated measurement period.

For availability evaluation the RSD has been considered as measurement without met mast. That means no wind directions or wind speed filters have been applied. The so evaluated data availability at the different measurement heights is shown in Figure 4.1. During the test the RSD operated without malfunction. To see how the applied RSD filter (*Windspeed of RSD <6 | (VAL1 >=300 | VAL2 >=300)* of chapter 3.4) decreases the data the RSD data where evaluated with and without the filter.

As can be seen in Figure 4.1, the availability of horizontal wind speed has values of up to about 78% for measurement heights between 40 m and 100 m when no filter is applied. Over 100 m the data availability decreases with increasing measurement height.

With RSD filter applied, the availability decreases by about 5%.

The data availability depends on weather during test, because during too heavy rain and wind the sodar writes "-9999" for values of horizontal wind speed.

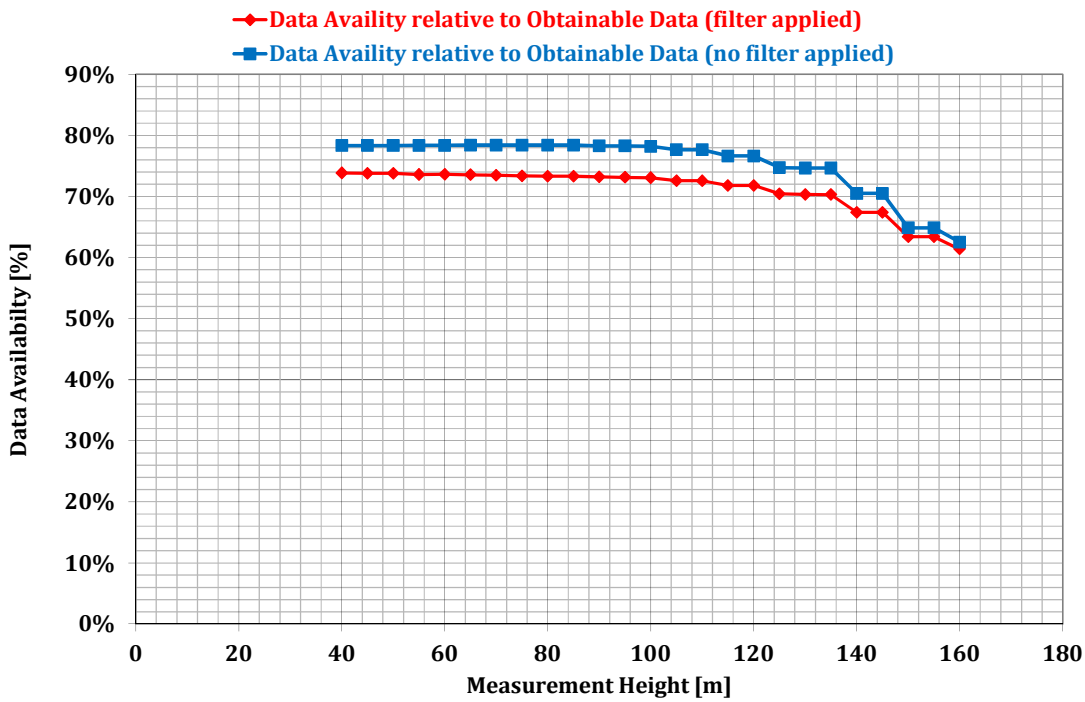

Figure 4.1 Availability of measurement of the horizontal wind speed component at different heights as measured by RSD.

4.2 Accuracy in Terms of the Horizontal Wind Speed Component

Detailed results of the comparison of cup anemometer measurement and measurement of the RSD in terms of the horizontal wind speed component are presented in the following sub chapters. The results can be summarised as follows:

- For the measurement heights between 140 m to 60 m the 10-minute mean values of the horizontal wind speed component as measured by the RSD and by cup anemometers show a good correlation (square of correlation coefficient about 0.94 to 0.96). Due to site effects the correlation decreases for lower measurement height (for 40 m to about 0.89).
- The averages of the horizontal wind speed between component between 135 m and 60 m are with values between -1.3% to 1% low. With increasing measurement height the averaged wind horizontal wind speed component shows a slightly tendency for underestimation (1% at 60m and -1.3% at 135m).
- For measurements height between 140 m and 60 m the horizontal wind speed component of the RSD show values of standard deviation of deviation of about 6-7%.
- The scatter plots of horizontal wind speed components show a good accuracy with a pleasable precision.

As the statistics gained from the 10-minute data can in principle be influenced by the distribution of data within the measurement period, the measurements of the RSD have been bin averaged against the cup anemometer measurements, and the bin wise deviation between the measurements has been analysed. For measurement heights between 140 m to 100 m the bin wise deviation of horizontal wind speed between met mast and RSD show in tendency values of underestimation for values between 4-8 m/s, where higher wind speeds between 8-12 m/s are slightly overestimated (Figure 4.4, Figure 4.8, Figure 4.10). For measurement heights over 120 m and wind speeds below 8 m/s and over 12 m/s some bin wise deviation are higher than uncertainty of anemometer.

The tendency for overestimating the horizontal wind speed component between 4-6 m/s increases with decreasing measurement height (Figure 4.2). For 100 m and 60 m the horizontal wind speed component is mostly lower than uncertainty of anemometer measurement (Figure 4.12, Figure 4.12, Figure 4.14).

As the measurements with the cup anemometers are traced back to national standards, the comparison between the cup anemometers and the RSD can be used in order to define an uncertainty of the wind speed measurement of the RSD. The following uncertainty components have been considered in order to evaluate the uncertainty of the measurements of the RSD:

- Wind tunnel calibration of the cup anemometers
- Classification of the cup anemometers according to IEC 61400-12-1
- Cup anemometer mounting effects
- Uncertainty of correction of mast effects on anemometers
- Bin wise deviation of RSD and cup anemometer measurements
- Statistical uncertainty of bin average of deviation of RSD and cup anemometer measurements

The different uncertainty components have been treated as independent uncertainties for the evaluation of the total uncertainty of the measurements of the RSD as gained from the comparison.

Total results like shown in right column of Table 4.1, etc. are given in expanded uncertainty. The expanded uncertainty assigned to the measurement results is obtained by multiplying 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%. To get the single uncertainty (*k*=1) with confidence of 68%, the expanded uncertainty has to be divided by two.

The resulting wind speed dependent uncertainties of the measurements of the horizontal wind speed component by the RSD are in the order of about 5-8% (expanded uncertainty *k*=2) in most wind speed bins for measurement height above 60 m. The variation of the uncertainty reaches from 4% to 23.9% for the different measurement heights and wind speed bins (Table 4.1 to Table 4.7)

It is noted that the uncertainty of the RSD as resulting from this comparison does not reflect all uncertainties of the system during an application at another site. The following additional uncertainties should be considered for an application of the system:

- The RSD measurements are influenced by environmental conditions, like e.g. wind shear. Thus, there is an additional uncertainty due to different environmental conditions during the calibration and during the application of the RSD.
- Mounting errors of the RSD during an application (vertical alignment)

Detailed ambient conditions dependent on wind speed and wind direction which were present during the test can be seen in Appendix A.

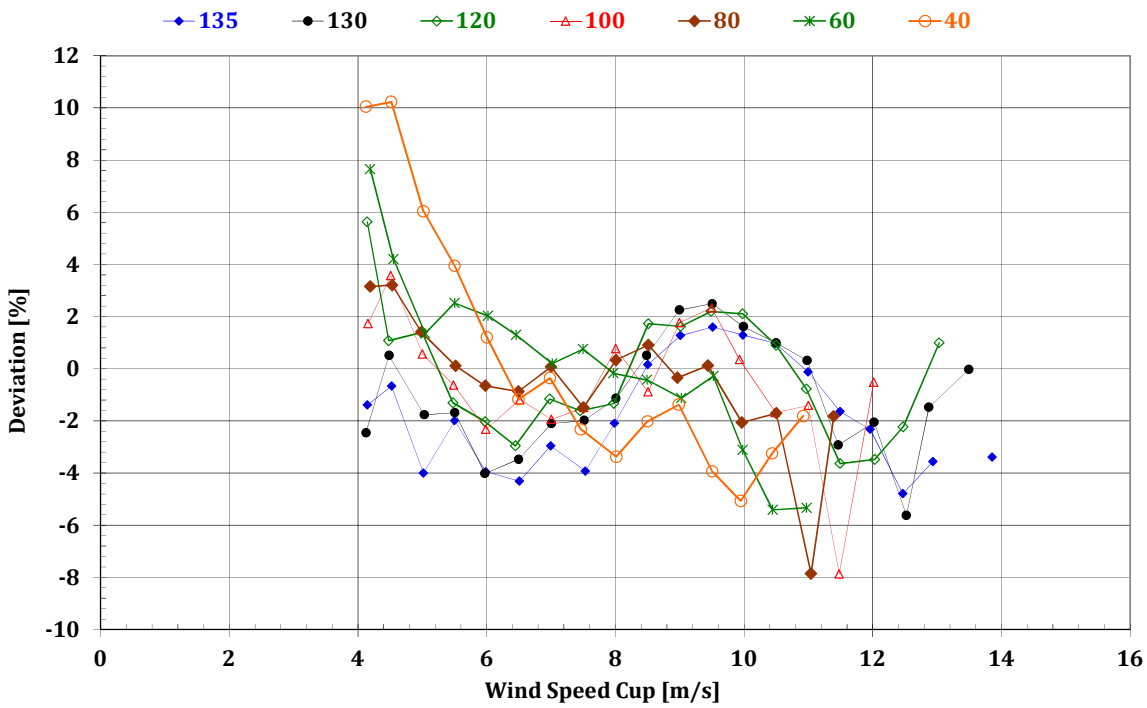

Figure 4.2 Overview of bin averaged deviations of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at several heights. A positive sign of the shown deviation represents higher values measured by RSD.

4.2.1 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 135 m Measurement Height

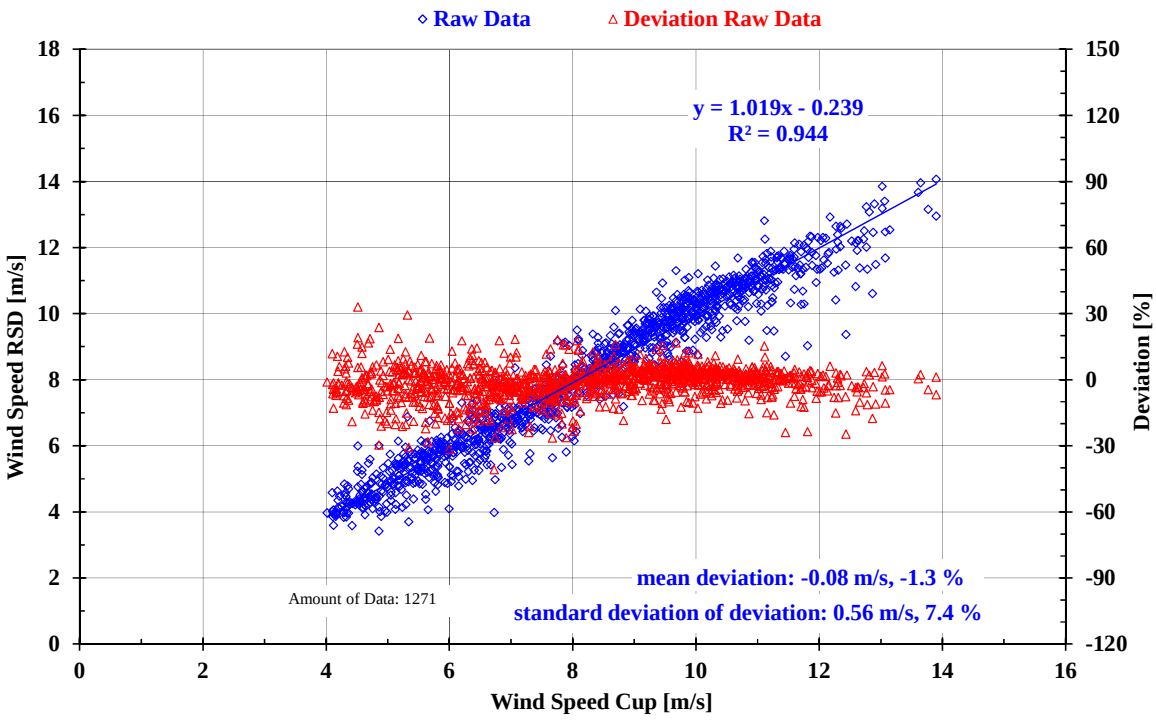

Figure 4.3 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 135 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

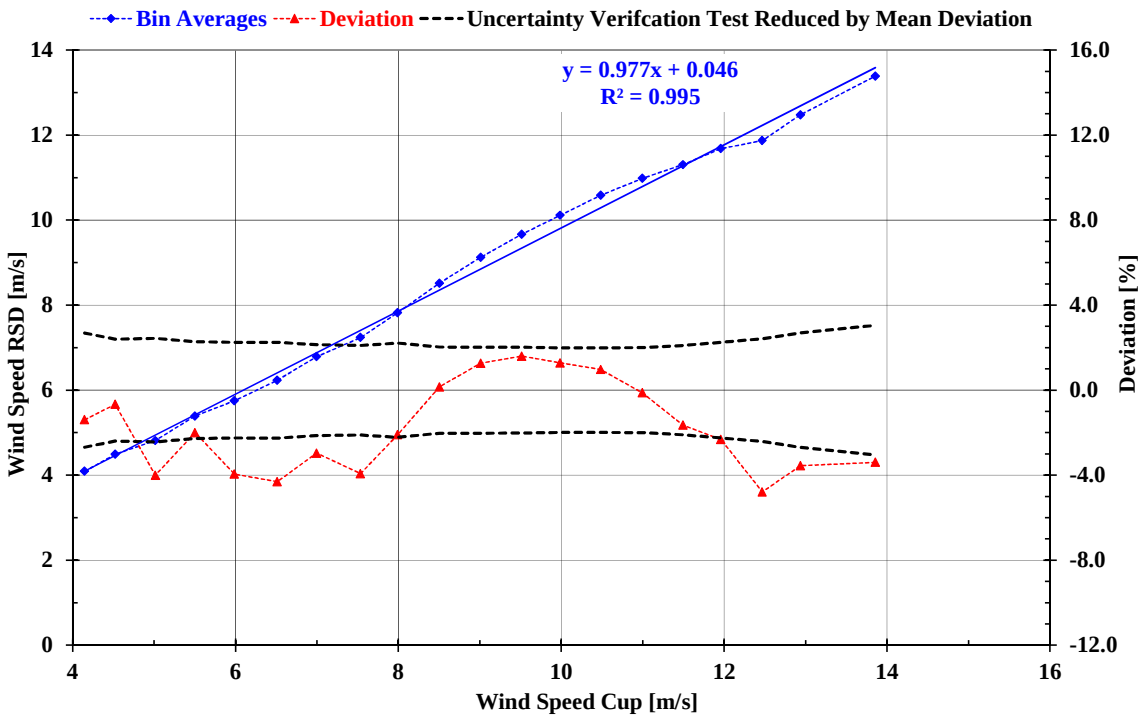

Figure 4.4: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 135 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.147	4.089	16	4.630	3.590	0.284	0.071	-0.058	5.4	0.223	6.1	0.251
4.522	4.492	63	6.000	3.580	0.446	0.056	-0.030	4.8	0.217	5.0	0.225
5.016	4.815	62	6.140	3.420	0.549	0.070	-0.201	4.9	0.244	9.4	0.470
5.503	5.393	84	6.880	3.700	0.516	0.056	-0.110	4.6	0.251	6.1	0.333
5.987	5.750	77	7.300	4.090	0.551	0.063	-0.237	4.5	0.269	9.1	0.544
6.511	6.230	84	7.370	3.980	0.621	0.068	-0.280	4.5	0.293	9.7	0.633
6.996	6.788	78	8.360	5.350	0.516	0.058	-0.207	4.3	0.300	7.3	0.511
7.534	7.238	79	8.710	5.540	0.524	0.059	-0.296	4.2	0.317	8.9	0.672
7.989	7.822	77	9.500	5.810	0.745	0.085	-0.167	4.4	0.354	6.1	0.488
8.504	8.518	92	10.090	7.400	0.473	0.049	0.013	4.1	0.345	4.1	0.346
9.011	9.125	79	10.130	7.190	0.490	0.055	0.114	4.0	0.364	4.8	0.430
9.514	9.666	104	11.300	7.800	0.566	0.055	0.152	4.0	0.384	5.1	0.489
9.985	10.113	107	11.210	8.540	0.501	0.048	0.128	4.0	0.398	4.7	0.474
10.483	10.585	78	11.680	9.290	0.454	0.051	0.102	4.0	0.417	4.4	0.464
10.996	10.983	80	12.810	9.190	0.549	0.061	-0.014	4.0	0.440	4.0	0.441
11.494	11.305	44	12.140	8.710	0.643	0.097	-0.189	4.2	0.483	5.3	0.613
11.960	11.681	27	12.920	9.030	0.749	0.144	-0.278	4.5	0.538	6.5	0.774
12.468	11.870	21	12.710	9.370	0.835	0.182	-0.597	4.8	0.602	10.7	1.338
12.936	12.476	14	13.850	10.610	0.940	0.251	-0.460	5.4	0.697	8.9	1.154
13.857	13.387	3	14.060	12.950	0.592	0.342	-0.471	6.1	0.845	9.1	1.264

Table 4.1 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 135 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.2 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 130 m Measurement Height

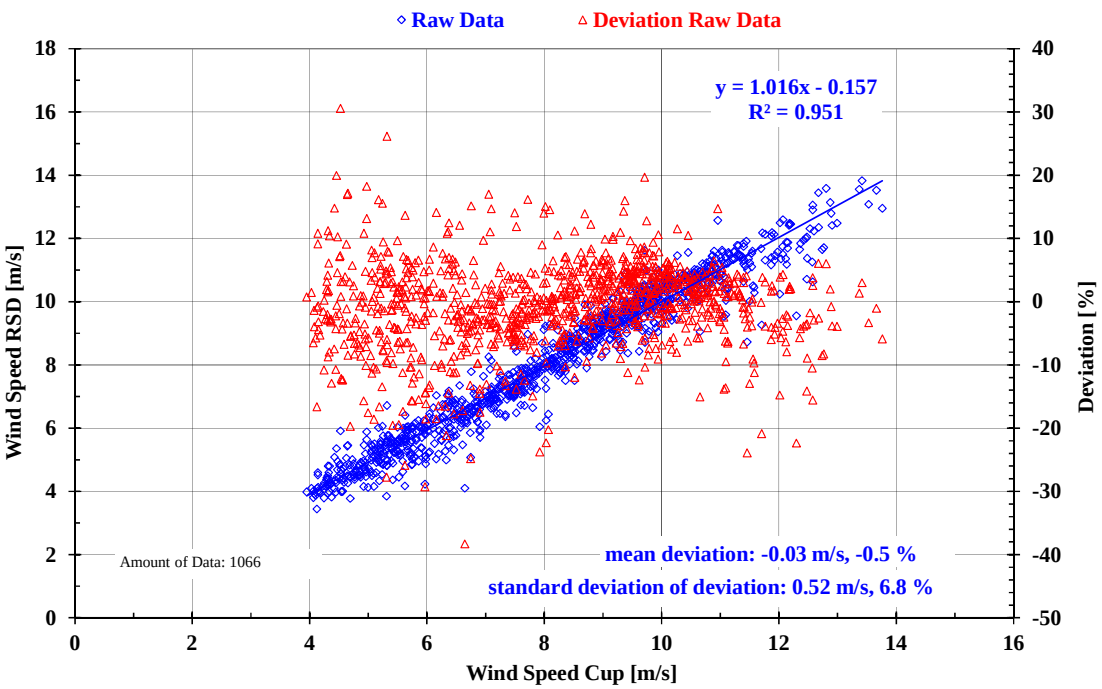

Figure 4.5 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 130 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

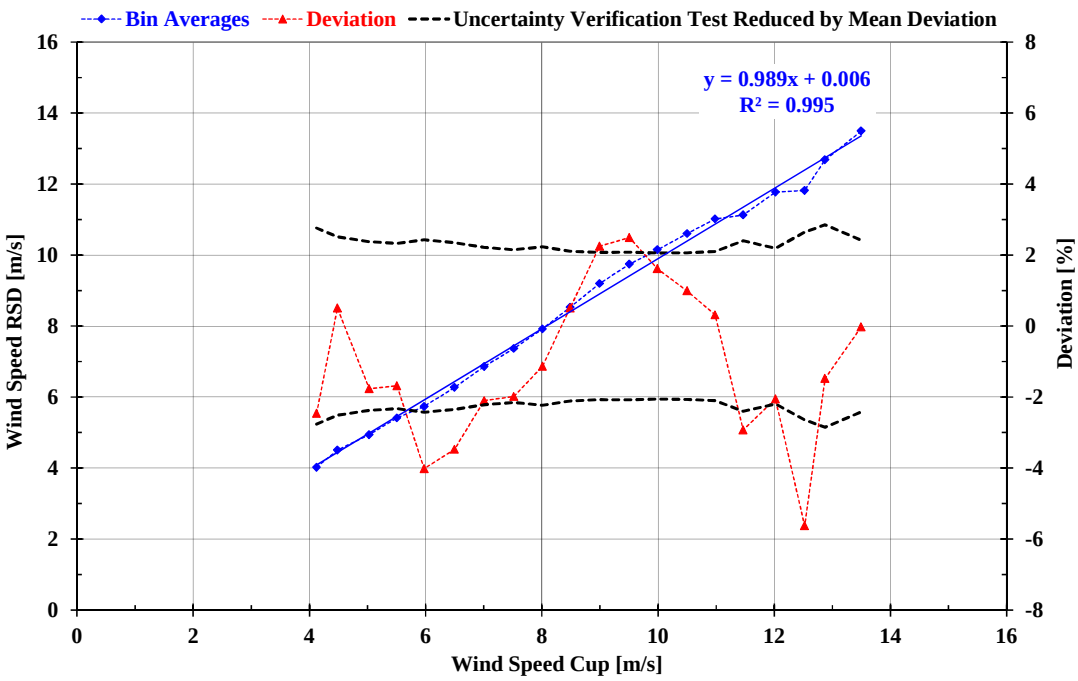

Figure 4.6 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.123	4.022	16	4.590	3.440	0.270	0.068	-0.101	5.5	0.228	7.4	0.305
4.482	4.504	54	5.910	3.770	0.436	0.059	0.023	5.0	0.225	5.1	0.230
5.029	4.941	61	6.060	4.120	0.457	0.058	-0.089	4.8	0.239	5.9	0.298
5.506	5.413	75	6.710	3.840	0.475	0.055	-0.093	4.7	0.256	5.7	0.316
5.975	5.735	52	7.030	4.220	0.553	0.077	-0.240	4.9	0.290	9.4	0.561
6.496	6.271	66	7.350	4.100	0.569	0.070	-0.226	4.7	0.305	8.4	0.545
7.007	6.860	63	8.250	5.700	0.479	0.060	-0.147	4.4	0.310	6.1	0.428
7.517	7.368	69	8.970	6.360	0.437	0.053	-0.149	4.3	0.323	5.9	0.440
8.011	7.920	62	9.270	6.040	0.616	0.078	-0.091	4.5	0.357	5.0	0.401
8.487	8.530	73	9.900	7.500	0.462	0.054	0.043	4.2	0.358	4.3	0.368
8.994	9.196	78	10.120	8.250	0.395	0.045	0.202	4.2	0.373	6.1	0.551
9.505	9.742	105	11.620	8.370	0.535	0.052	0.237	4.2	0.395	6.5	0.617
9.988	10.150	89	11.000	8.950	0.450	0.048	0.161	4.1	0.412	5.2	0.523
10.499	10.603	65	11.550	9.050	0.418	0.052	0.104	4.1	0.434	4.6	0.481
10.981	11.016	56	12.570	9.530	0.514	0.069	0.035	4.2	0.461	4.2	0.466
11.464	11.129	29	12.170	8.720	0.782	0.145	-0.336	4.8	0.551	7.6	0.868
12.020	11.774	25	12.590	10.240	0.569	0.114	-0.247	4.4	0.527	6.0	0.722
12.522	11.818	17	13.440	9.550	0.952	0.231	-0.704	5.3	0.662	12.4	1.557
12.873	12.683	6	13.580	11.710	0.645	0.263	-0.190	5.7	0.734	6.4	0.827
13.496	13.493	4	13.820	13.080	0.306	0.153	-0.003	4.8	0.653	4.8	0.653

Table 4.2 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.3 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 120 m Measurement Height

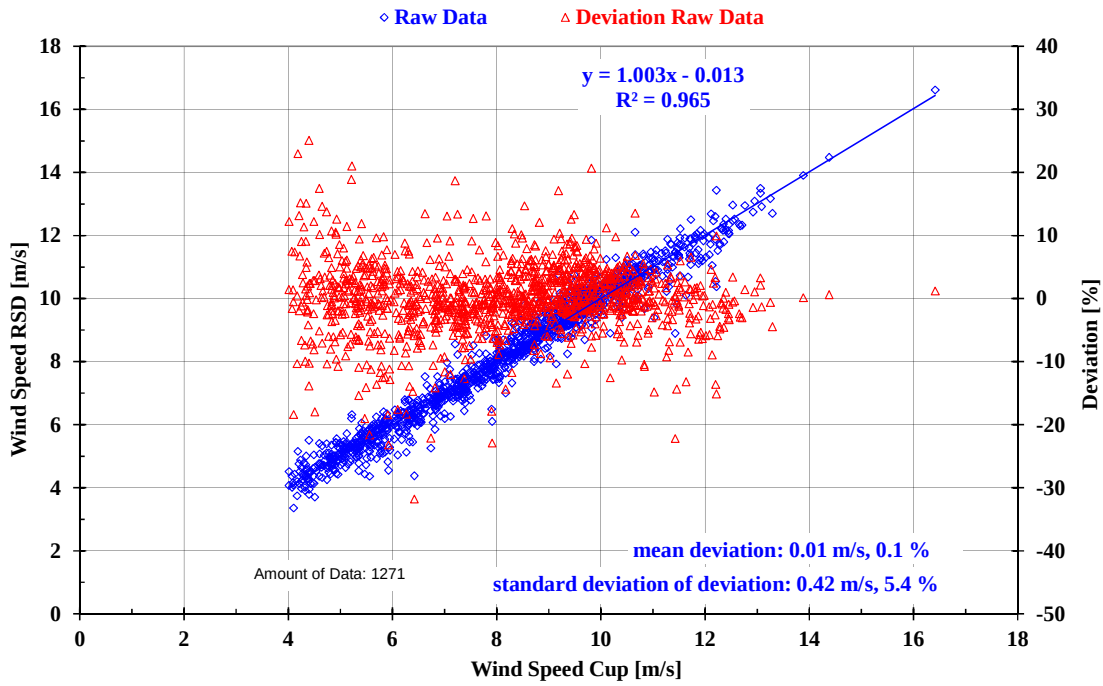

Figure 4.7 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 120 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

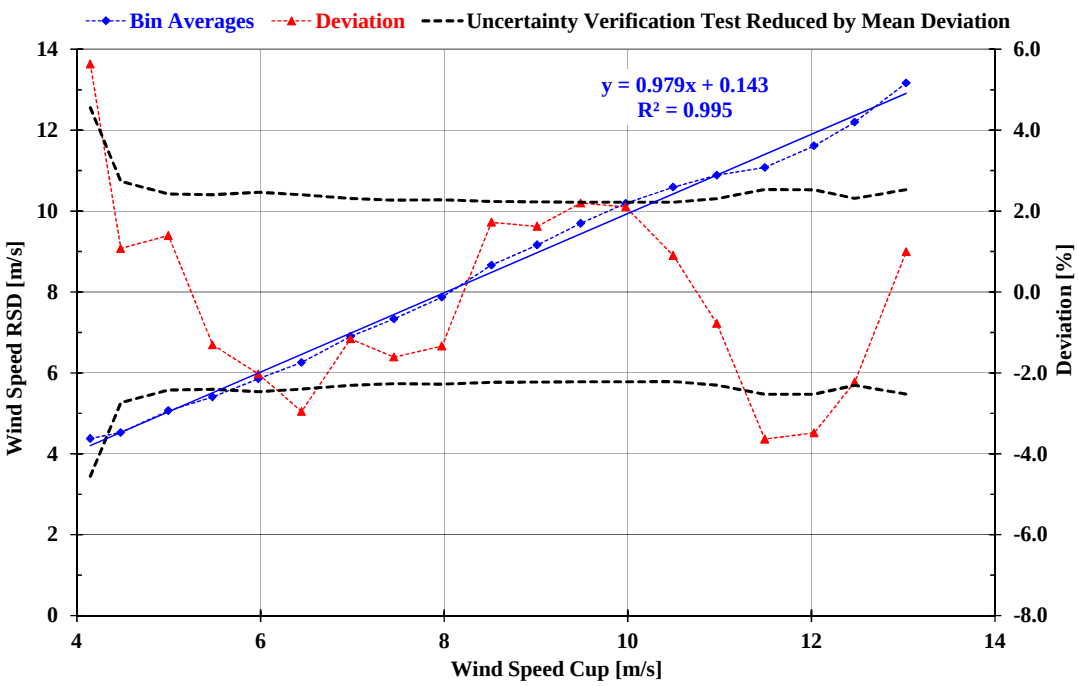

Figure 4.8 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.145	4.378	10	5.150	3.350	0.536	0.169	0.233	9.1	0.378	14.5	0.601
4.477	4.526	41	5.500	3.700	0.455	0.071	0.048	5.5	0.245	5.9	0.263
4.996	5.066	64	6.320	4.420	0.377	0.047	0.070	4.8	0.242	5.6	0.279
5.477	5.406	67	6.240	4.360	0.398	0.049	-0.072	4.8	0.263	5.5	0.300
5.978	5.856	53	6.790	4.550	0.494	0.068	-0.121	4.9	0.295	6.4	0.381
6.448	6.257	61	7.520	4.380	0.494	0.063	-0.190	4.8	0.310	7.6	0.491
6.981	6.900	65	8.550	5.850	0.428	0.053	-0.081	4.6	0.322	5.2	0.361
7.453	7.333	69	8.510	6.440	0.386	0.046	-0.120	4.5	0.338	5.6	0.415
7.976	7.869	74	8.820	6.100	0.452	0.052	-0.107	4.6	0.364	5.3	0.422
8.515	8.662	86	9.790	7.320	0.421	0.045	0.147	4.5	0.381	5.6	0.481
9.015	9.161	90	10.760	7.920	0.456	0.048	0.146	4.5	0.402	5.5	0.497
9.488	9.697	93	10.750	8.240	0.447	0.046	0.208	4.4	0.421	6.2	0.593
9.979	10.189	78	11.850	8.900	0.449	0.051	0.210	4.4	0.443	6.1	0.610
10.497	10.591	64	12.100	9.390	0.444	0.055	0.095	4.4	0.465	4.8	0.502
10.971	10.885	32	11.530	9.390	0.523	0.093	-0.085	4.6	0.506	4.9	0.534
11.493	11.075	25	12.210	8.890	0.787	0.157	-0.418	5.1	0.582	8.9	1.019
12.031	11.612	20	13.430	10.370	0.711	0.159	-0.419	5.0	0.607	8.6	1.035
12.473	12.195	10	12.960	11.690	0.407	0.129	-0.278	4.6	0.576	6.4	0.801
13.034	13.163	3	13.490	12.910	0.297	0.171	0.130	5.1	0.659	5.4	0.708

Table 4.3 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.4 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 100 m Measurement Height

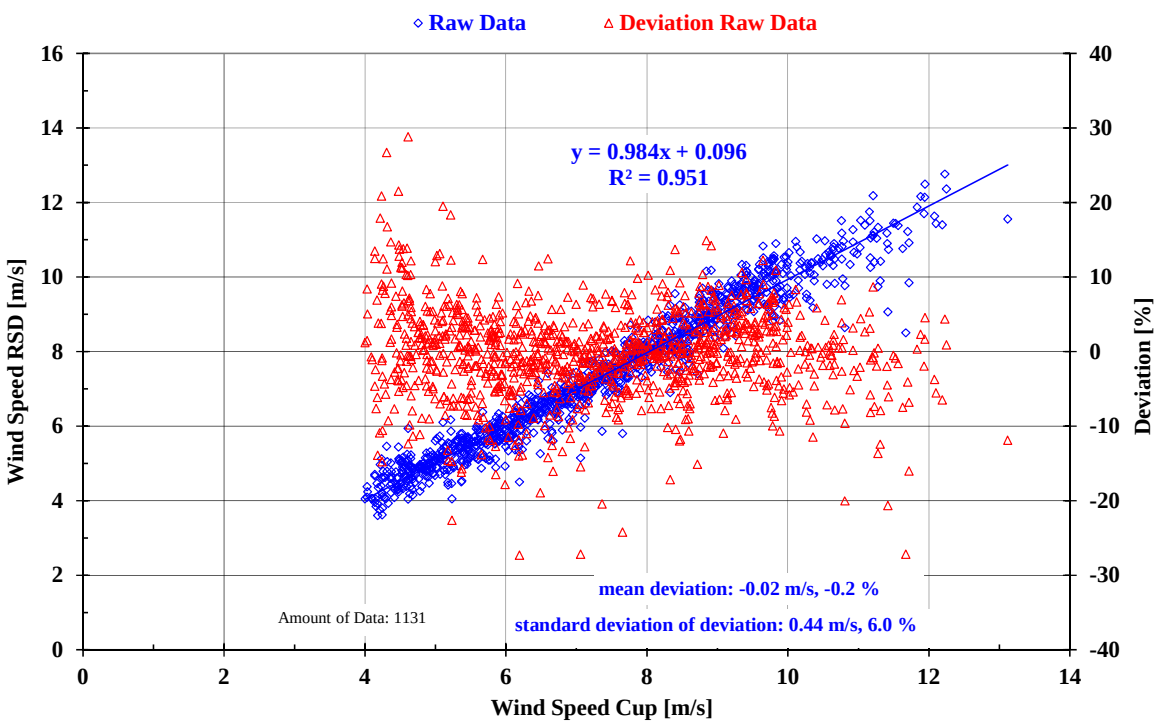

Figure 4.9 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 100 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

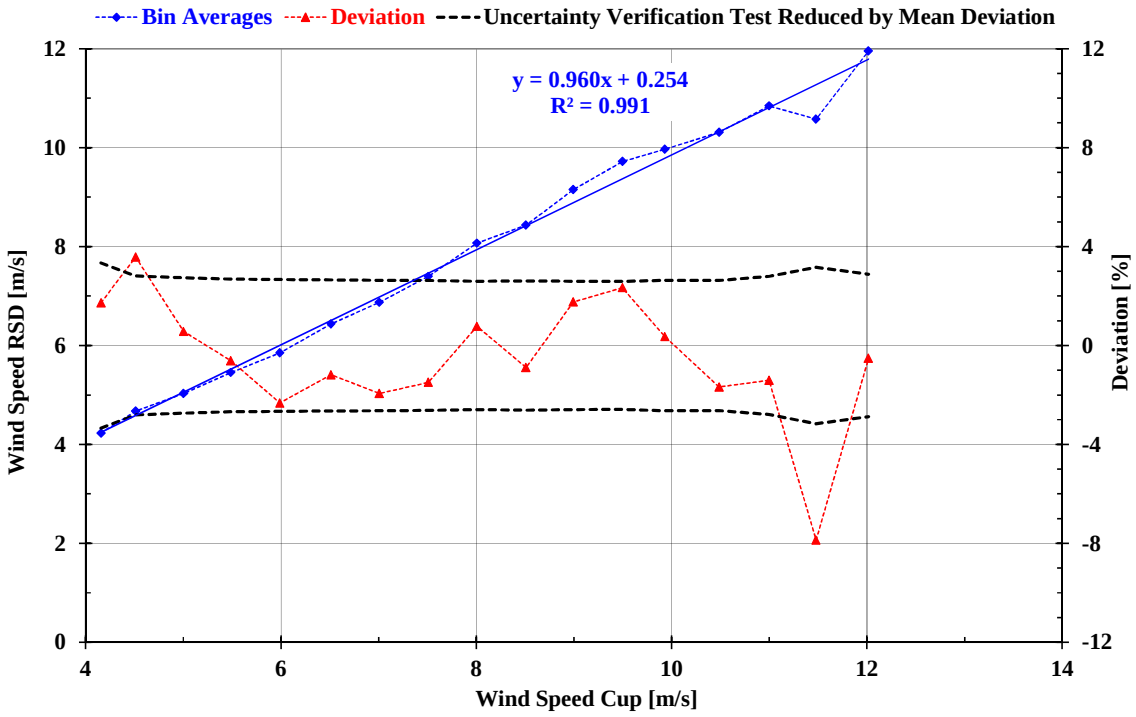

Figure 4.10 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 100 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.157	4.229	23	5.120	3.600	0.398	0.083	0.072	6.7	0.278	7.5	0.313
4.512	4.673	84	5.940	3.800	0.377	0.041	0.161	5.6	0.254	9.1	0.410
5.003	5.032	90	6.170	4.050	0.367	0.039	0.028	5.5	0.274	5.6	0.280
5.487	5.453	88	6.370	4.500	0.310	0.033	-0.034	5.4	0.294	5.5	0.302
5.989	5.850	104	6.730	4.500	0.368	0.036	-0.139	5.3	0.319	7.1	0.424
6.513	6.436	88	7.420	5.260	0.359	0.038	-0.077	5.3	0.345	5.8	0.378
7.008	6.872	86	7.750	5.140	0.403	0.043	-0.136	5.3	0.370	6.6	0.459
7.509	7.397	86	8.290	5.800	0.407	0.044	-0.112	5.3	0.394	6.0	0.453
8.006	8.068	86	8.970	7.300	0.346	0.037	0.062	5.2	0.415	5.4	0.433
8.508	8.433	96	9.550	6.900	0.489	0.050	-0.076	5.2	0.445	5.5	0.470
8.995	9.154	87	10.180	8.090	0.416	0.045	0.159	5.2	0.467	6.3	0.564
9.496	9.718	74	10.830	8.420	0.419	0.049	0.222	5.2	0.491	7.0	0.662
9.931	9.967	54	10.950	8.810	0.550	0.075	0.035	5.3	0.524	5.3	0.529
10.487	10.311	31	11.020	9.170	0.476	0.085	-0.176	5.3	0.552	6.2	0.654
10.999	10.843	26	12.180	8.640	0.716	0.140	-0.155	5.6	0.615	6.3	0.689
11.479	10.576	17	11.440	8.500	0.877	0.213	-0.903	6.3	0.726	17.0	1.946
12.016	11.953	9	12.760	11.400	0.471	0.157	-0.063	5.8	0.692	5.9	0.703

Table 4.4 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 100 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.5 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 80 m Measurement Height

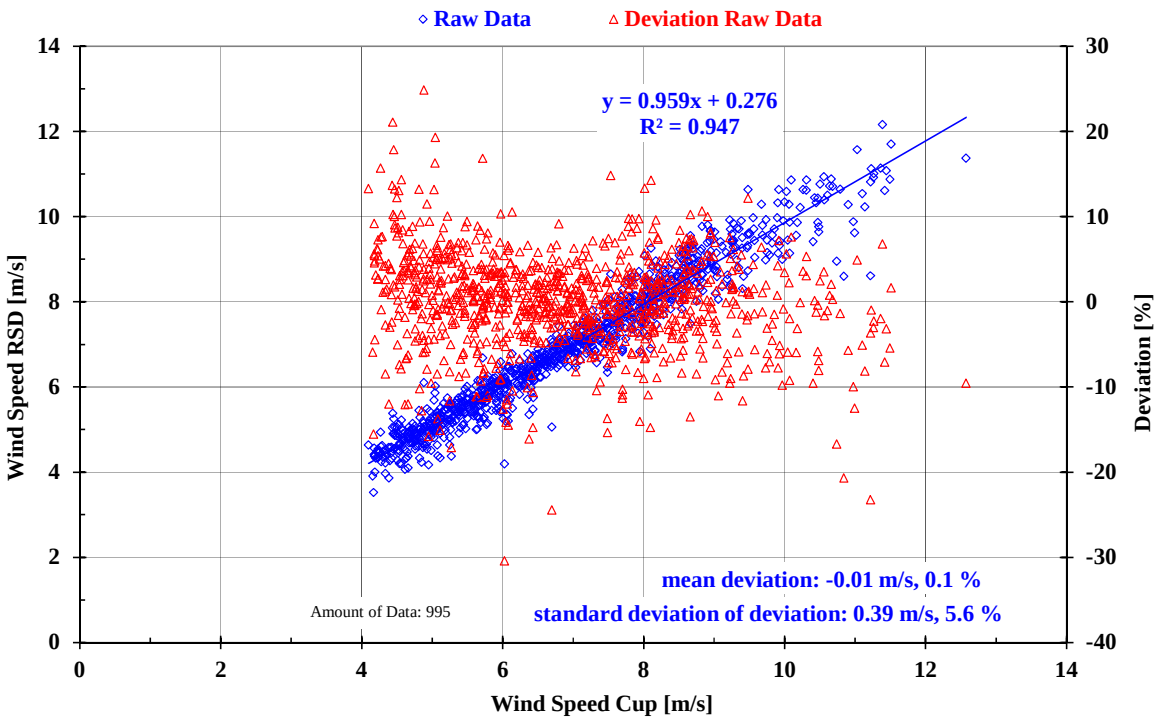

Figure 4.11 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 80 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

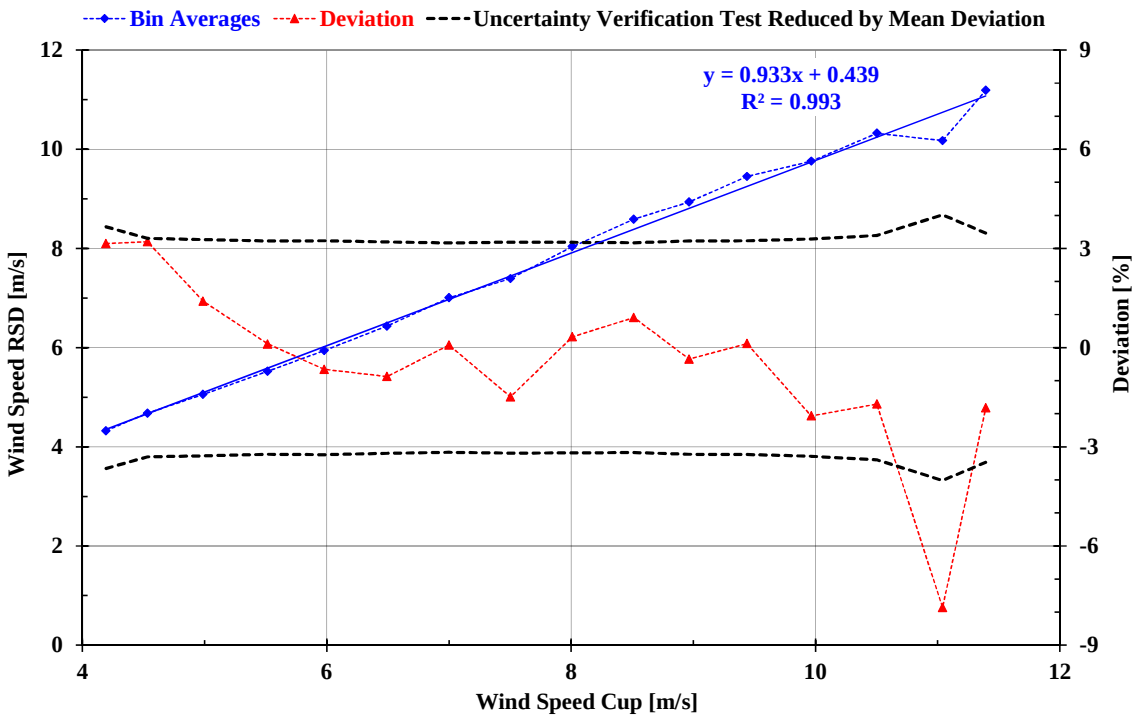

Figure 4.12 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 80 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.193	4.325	16	4.640	3.520	0.285	0.071	0.132	7.3	0.306	9.6	0.404
4.532	4.677	81	5.380	3.860	0.311	0.035	0.145	6.6	0.300	9.2	0.417
4.987	5.057	99	6.100	4.170	0.365	0.037	0.070	6.5	0.326	7.1	0.355
5.516	5.522	106	6.680	4.370	0.328	0.032	0.006	6.5	0.356	6.5	0.356
5.978	5.939	96	6.780	4.190	0.391	0.040	-0.039	6.5	0.387	6.6	0.395
6.493	6.437	96	7.110	5.060	0.339	0.035	-0.057	6.4	0.415	6.6	0.430
7.000	7.006	95	7.620	6.450	0.259	0.027	0.005	6.3	0.444	6.3	0.444
7.503	7.392	85	8.650	6.340	0.409	0.044	-0.112	6.4	0.479	7.0	0.529
8.010	8.037	97	9.260	6.830	0.447	0.045	0.026	6.4	0.510	6.4	0.513
8.514	8.591	79	9.550	7.490	0.423	0.048	0.077	6.3	0.540	6.6	0.562
8.966	8.934	49	9.920	8.010	0.486	0.069	-0.031	6.4	0.578	6.5	0.581
9.440	9.451	34	10.630	8.310	0.464	0.080	0.011	6.5	0.610	6.5	0.611
9.965	9.760	24	10.860	8.990	0.542	0.111	-0.206	6.6	0.655	7.8	0.773
10.502	10.323	18	10.930	8.950	0.565	0.133	-0.179	6.8	0.713	7.6	0.798
11.040	10.173	11	11.570	8.600	0.945	0.285	-0.868	8.0	0.887	17.7	1.949
11.394	11.186	8	12.160	10.610	0.501	0.177	-0.207	6.9	0.790	7.8	0.892

Table 4.5 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 80 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.6 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 60 m Measurement Height

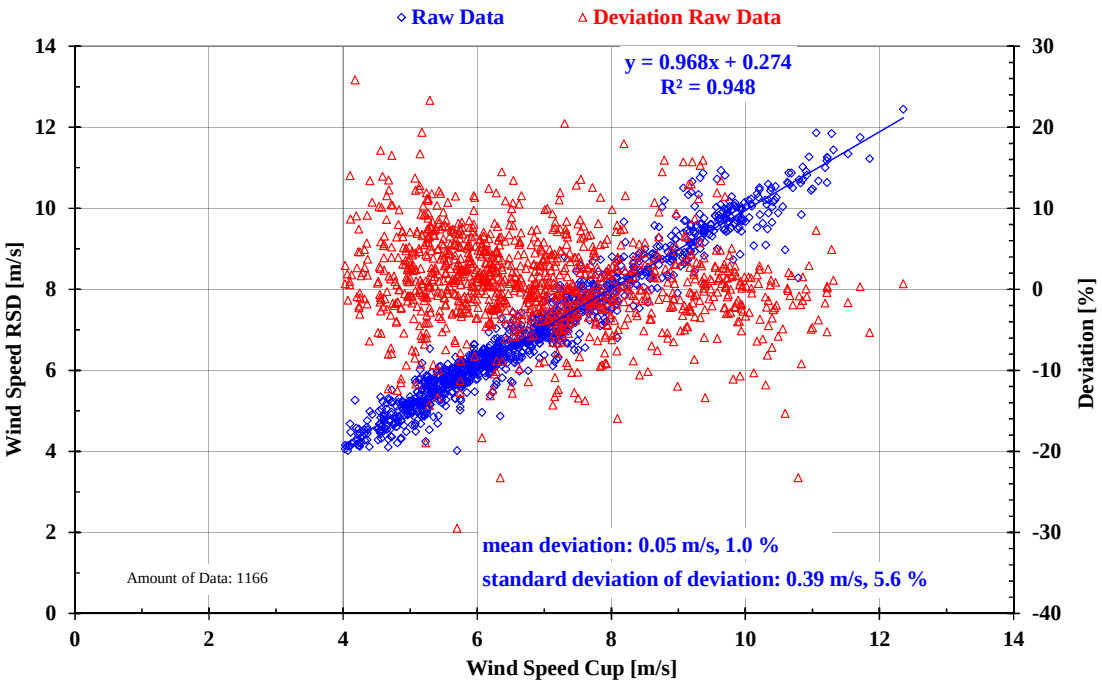

Figure 4.13 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 60 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

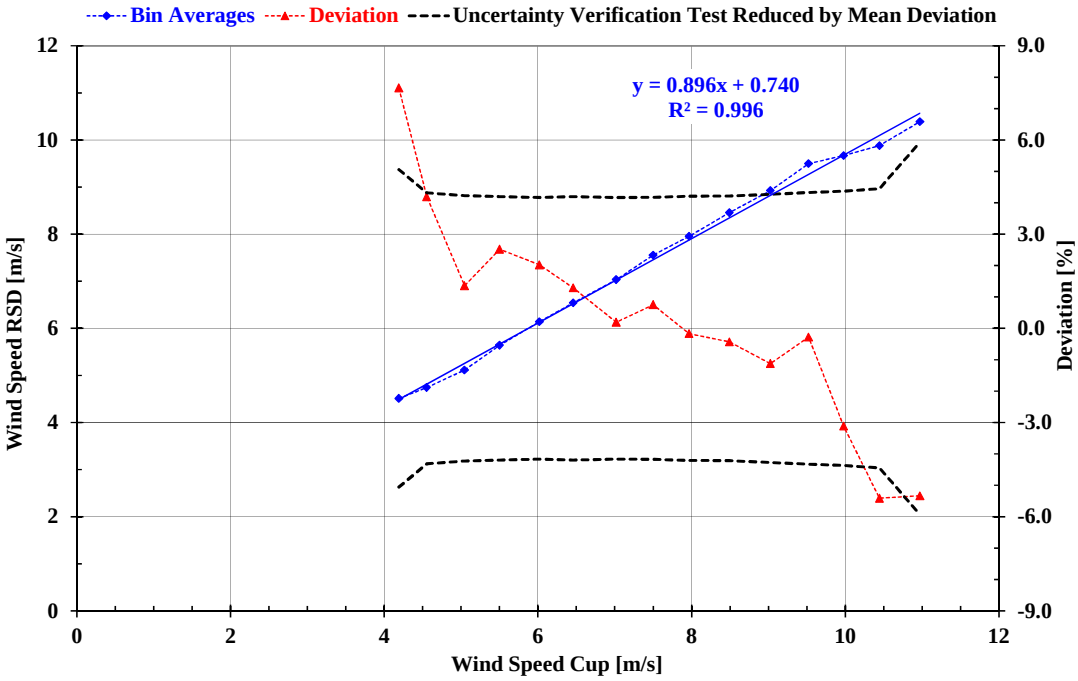

Figure 4.14 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.190	4.511	9	5.260	4.150	0.333	0.111	0.321	10.1	0.424	18.3	0.769
4.552	4.743	44	5.510	4.100	0.357	0.054	0.191	8.6	0.393	12.0	0.548
5.045	5.114	93	6.180	4.210	0.384	0.040	0.068	8.5	0.426	8.9	0.448
5.501	5.639	119	6.530	4.020	0.368	0.034	0.139	8.4	0.462	9.8	0.539
6.020	6.142	121	6.940	4.960	0.301	0.027	0.122	8.3	0.501	9.3	0.557
6.457	6.541	85	7.430	4.870	0.447	0.048	0.083	8.4	0.542	8.8	0.567
7.019	7.033	97	8.100	5.990	0.427	0.043	0.014	8.3	0.585	8.3	0.586
7.499	7.555	85	8.800	6.500	0.482	0.052	0.056	8.3	0.626	8.5	0.636
7.969	7.955	56	9.660	6.800	0.546	0.073	-0.014	8.4	0.670	8.4	0.671
8.492	8.456	32	9.570	7.530	0.495	0.087	-0.036	8.4	0.716	8.5	0.719
9.026	8.925	26	10.390	7.910	0.594	0.117	-0.101	8.5	0.771	8.8	0.797
9.524	9.497	15	10.090	8.140	0.554	0.143	-0.027	8.6	0.824	8.7	0.826
9.980	9.669	13	10.460	8.730	0.550	0.152	-0.311	8.7	0.872	10.7	1.071
10.445	9.880	10	10.620	8.970	0.579	0.183	-0.565	8.9	0.929	14.0	1.463
10.972	10.387	6	11.860	8.280	1.245	0.508	-0.585	11.9	1.301	15.9	1.750

Table 4.6 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.2.7 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 40 m Measurement Height

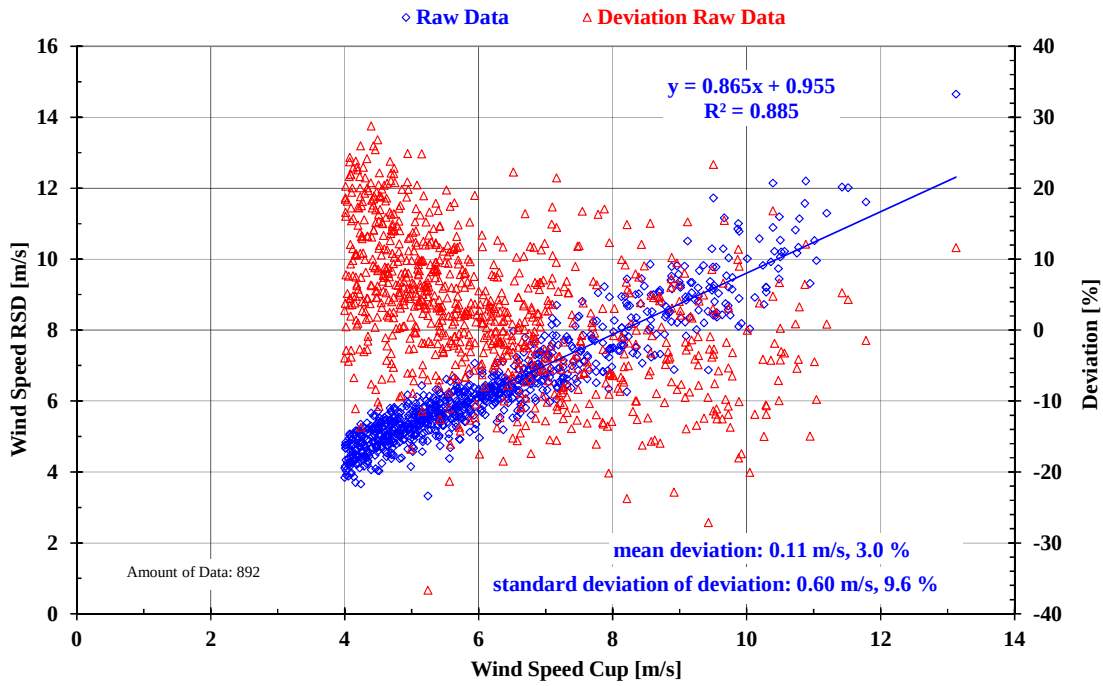

Figure 4.15 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 40 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

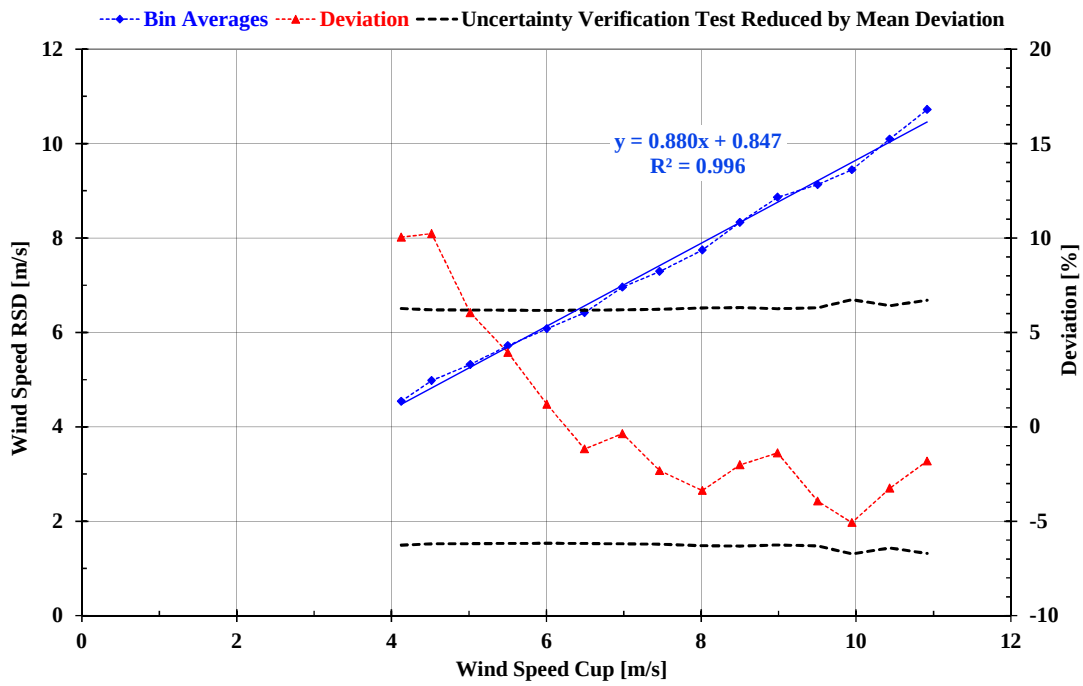

Figure 4.16 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 40 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

v (Refer-ence)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Refer-ence)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.126	4.540	70	5.340	3.660	0.400	0.048	0.414	12.5	0.517	23.7	0.977
4.518	4.980	138	5.820	4.030	0.410	0.035	0.462	12.4	0.560	23.9	1.081
5.016	5.320	120	6.430	3.320	0.431	0.039	0.303	12.4	0.621	17.3	0.868
5.503	5.719	113	6.650	4.380	0.431	0.041	0.217	12.4	0.680	14.6	0.806
6.005	6.078	80	7.070	4.960	0.391	0.044	0.072	12.3	0.740	12.6	0.754
6.494	6.418	80	7.970	5.190	0.495	0.055	-0.076	12.3	0.802	12.6	0.816
6.984	6.959	69	8.700	5.600	0.605	0.073	-0.025	12.4	0.866	12.4	0.867
7.465	7.291	42	8.810	6.360	0.610	0.094	-0.174	12.4	0.929	13.3	0.992
8.015	7.745	40	9.440	6.260	0.804	0.127	-0.271	12.6	1.009	14.3	1.145
8.502	8.330	31	9.850	7.070	0.772	0.139	-0.172	12.6	1.073	13.3	1.127
8.987	8.863	32	10.510	6.880	0.724	0.128	-0.124	12.5	1.124	12.8	1.151
9.506	9.131	34	11.720	6.870	0.913	0.157	-0.374	12.6	1.199	14.9	1.414
9.949	9.444	14	11.000	8.030	1.075	0.287	-0.504	13.5	1.340	16.9	1.677
10.436	10.097	16	12.140	8.720	0.891	0.223	-0.339	12.8	1.339	14.4	1.502
10.919	10.721	9	12.200	9.310	0.900	0.300	-0.198	13.4	1.463	13.9	1.516

Table 4.7 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 40 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3 Accuracy of the RSD in Terms of Wind Shear

Wind shear exponents have been calculated for each 10-minute period from the measurements of the RSD and the measurements of the met mast at nearly same measurement heights as explained in chapter 3.3.3.

Detailed results of the comparison of shear exponents are presented in the following sub chapters.

The following conclusions can be drawn:

- The comparison of the shear exponents derived from the measurements of the RSD and the cup anemometer measurements for each 10-minute period shows poor correlation (Figure 4.17, Figure 4.19, Figure 4.21, Figure 4.23, Figure 4.25 and Figure 4.27). The square of the correlation coefficient is about 0.23 to 0.5 in the different height ranges.
- The bin-averaged wind shear exponents derived from the measurements of the RSD and the cup anemometer measurements show a moderate correlation with a squared correlation coefficient of about 0.74 – 0.95 for measurement height between 40m and 135m.
- The standard deviation of deviation of the mean shear exponents gained by RSD slightly increase with increasing measurement height from 0.143 to 0.39.

In all height levels, the bin averaged difference in wind shear exponent between cup anemometers and RSD shows strong wind shear dependence. The RSD mostly overestimates wind shear at low shear exponents and slightly underestimates at high wind shears. A clear property on which shear exponent the value gets from negative to positive can't be seen.

The comparison of the shear exponents measured by the cup anemometers and by the RSD can be used in order to define an uncertainty of the measurement of the wind shear of the RSD. The following components have been considered in order to evaluate this uncertainty:

- Wind tunnel calibration of cup anemometers
- Classification of the cup anemometers according to IEC 61400-12-1
- Cup anemometer mounting effects
- Uncertainty of correction of mast effects on anemometers
- Bin wise deviation of RSD and cup anemometer measurements in terms of the wind shear
- Statistical uncertainty of bin average of deviation of RSD and cup anemometer measurements in terms of the wind shear

The respective uncertainties of the two cup anemometer measurements applied to evaluate the reference wind shear have been cumulated under careful and conservative consideration of the correlation of the uncertainties between the cup anemometers. The uncertainty components listed above have then been treated as independent uncertainties for the evaluation of the total uncertainty of the wind shear measurement by the RSD as gained from the comparison.

The resulting standard uncertainty of the RSD measurements in terms of the wind shear exponents is mostly below 0.1 *(k=2)* for a shear range of 0.1 to 0.4 in all height ranges with the exception of wind shear between 40 and 60 m and between 135 m and 120 m.

This is considered as good. For negative wind shear and high wind shear above 0.5 uncertainty increases significantly to values of 0.3 and more. This is considered unfavourably for sites with such wind shear conditions.

4.3.1 Accuracy of RSD in Terms of Wind Shear between 135 m and 120 m

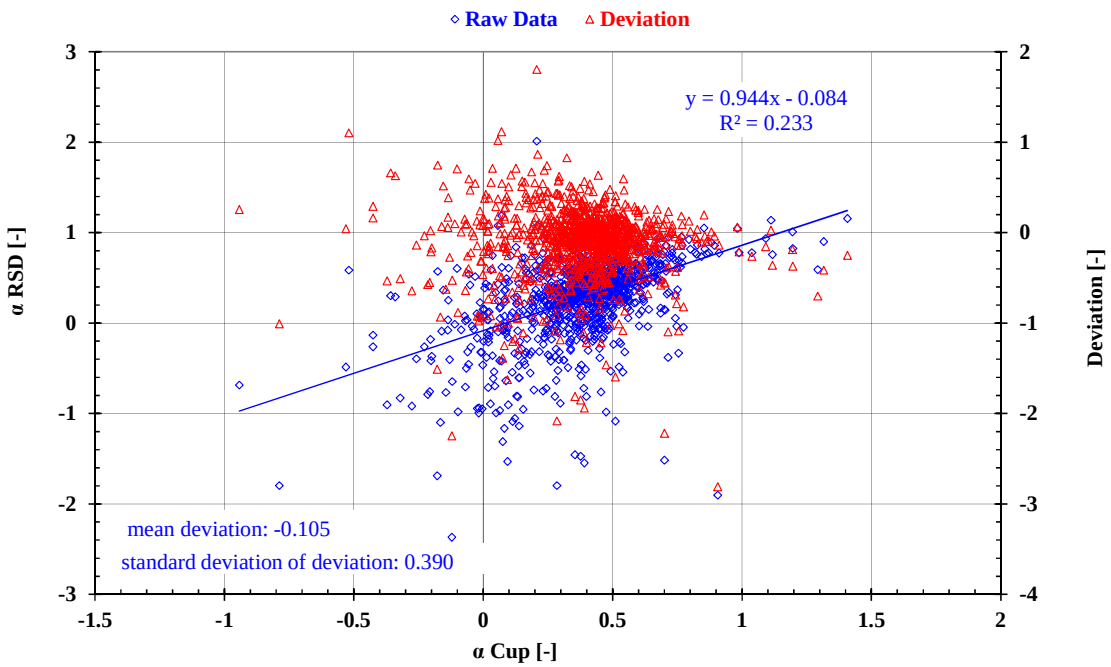

Figure 4.17: Scatter plot of shear exponents as measured by RSD between 135 m and 120 m height against cup anemometer measurements between 135 m and 120.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

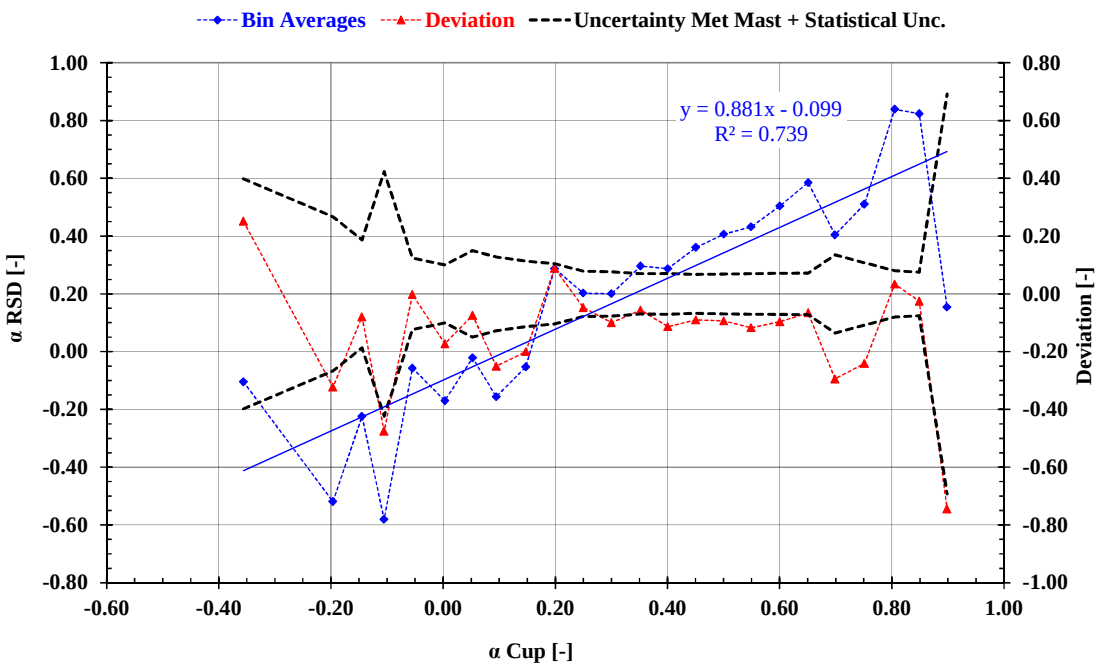

Figure 4.18: Bin analysis of shear exponents measured by RSD between 135 m and 120 m against cup anemometer measurements between 135 m and 120.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.356	-0.105	3	0.302	-0.906	0.694	0.393	0.251	0.941
-0.197	-0.519	7	0.571	-1.690	0.687	0.259	-0.323	0.838
-0.145	-0.224	8	0.362	-1.099	0.503	0.176	-0.080	0.407
-0.105	-0.581	6	0.603	-2.368	1.033	0.419	-0.475	1.273
-0.055	-0.057	13	0.538	-0.708	0.391	0.107	-0.002	0.248
0.003	-0.170	28	0.433	-0.995	0.420	0.078	-0.173	0.400
0.053	-0.021	22	1.186	-0.994	0.641	0.136	-0.074	0.334
0.095	-0.156	30	0.744	-1.532	0.609	0.111	-0.251	0.563
0.147	-0.053	32	0.839	-1.140	0.534	0.094	-0.201	0.460
0.199	0.287	35	2.012	-0.741	0.497	0.084	0.089	0.274
0.250	0.203	58	0.986	-0.752	0.357	0.047	-0.047	0.183
0.300	0.201	88	1.151	-1.797	0.416	0.044	-0.100	0.252
0.352	0.296	115	0.864	-1.457	0.321	0.030	-0.056	0.179
0.401	0.287	131	0.957	-1.548	0.372	0.032	-0.114	0.268
0.451	0.360	142	1.079	-0.764	0.280	0.023	-0.090	0.225
0.500	0.407	112	0.968	-1.085	0.300	0.028	-0.093	0.232
0.549	0.432	80	1.139	-0.543	0.281	0.031	-0.117	0.273
0.600	0.504	42	0.881	-0.032	0.214	0.033	-0.096	0.239
0.651	0.585	30	0.929	-0.040	0.190	0.034	-0.066	0.195
0.699	0.404	21	0.950	-1.518	0.547	0.120	-0.294	0.648
0.751	0.510	18	0.949	-0.333	0.370	0.088	-0.241	0.528
0.805	0.839	3	0.923	0.778	0.075	0.050	0.034	0.174
0.849	0.824	7	1.049	0.735	0.108	0.041	-0.025	0.159
0.899	0.154	4	0.891	-1.904	1.373	0.689	-0.745	2.034

Table 4.8: Bin analysis of shear exponents measured by RSD between 135 m and 120 m against cup anemometer measurements between 135 m and 120.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3.2 Accuracy of RSD in Terms of Wind Shear between 135 m and 100 m

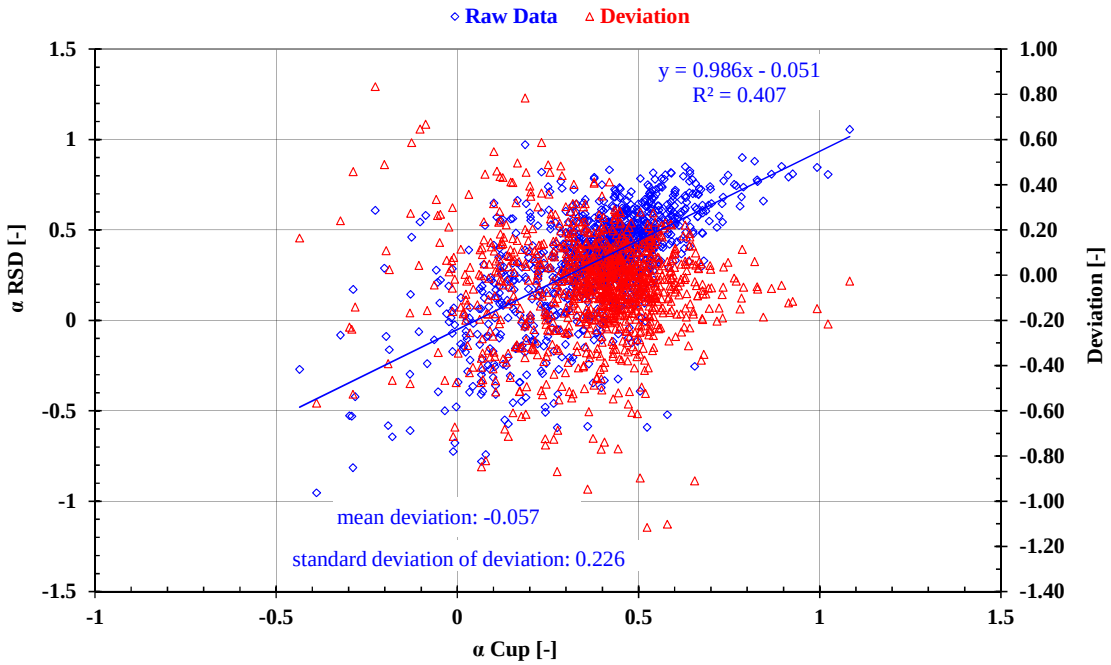

Figure 4.19: Scatter plot of shear exponents as measured by RSD between 135 m and 100 m height against cup anemometer measurements between 135 m and 100.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

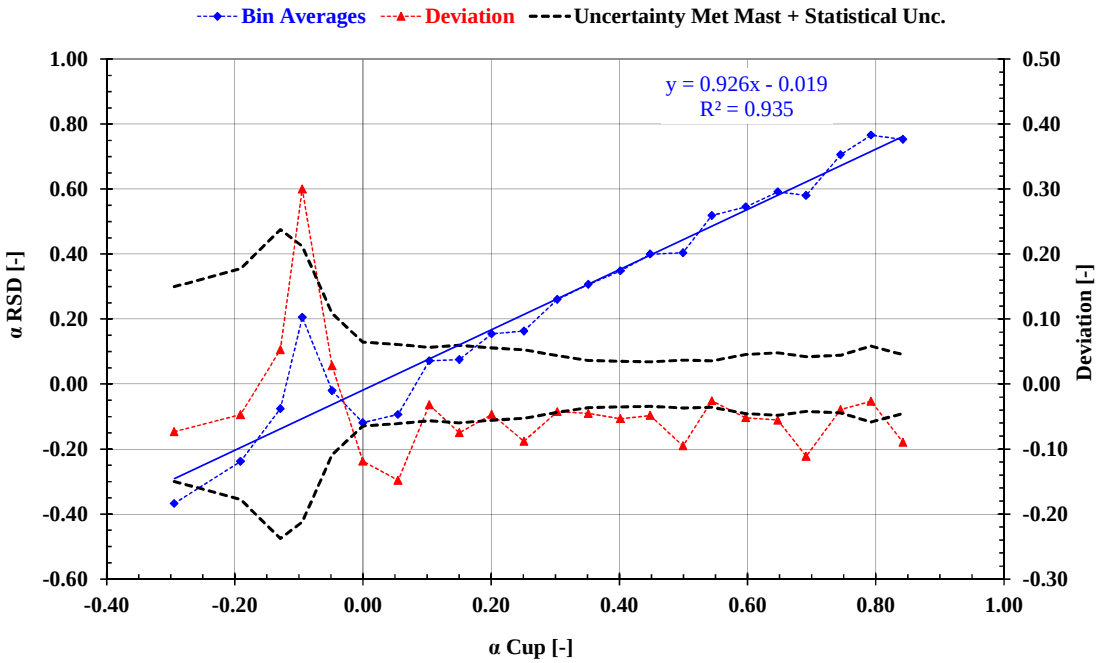

Figure 4.20: Bin analysis of shear exponents measured by RSD between 135 m and 100 m against cup anemometer measurements between 135 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.294	-0.368	6	0.170	-0.815	0.354	0.146	-0.073	0.334
-0.191	-0.238	5	0.288	-0.645	0.384	0.175	-0.047	0.367
-0.129	-0.076	4	0.460	-0.610	0.473	0.236	0.053	0.487
-0.095	0.205	4	0.580	-0.239	0.418	0.210	0.300	0.735
-0.048	-0.020	8	0.277	-0.500	0.292	0.104	0.028	0.225
0.000	-0.119	21	0.285	-0.725	0.257	0.056	-0.119	0.270
0.055	-0.093	27	0.388	-0.780	0.270	0.052	-0.148	0.320
0.103	0.072	40	0.648	-0.742	0.301	0.047	-0.032	0.130
0.150	0.075	39	0.663	-0.573	0.315	0.051	-0.075	0.191
0.201	0.154	42	0.971	-0.449	0.299	0.046	-0.047	0.145
0.251	0.163	52	0.820	-0.509	0.304	0.042	-0.088	0.205
0.303	0.261	73	0.768	-0.593	0.262	0.030	-0.042	0.122
0.352	0.307	113	0.669	-0.587	0.192	0.018	-0.045	0.116
0.402	0.348	152	0.832	-0.372	0.196	0.016	-0.053	0.128
0.448	0.400	163	0.734	-0.325	0.177	0.014	-0.048	0.119
0.499	0.404	118	0.784	-0.592	0.207	0.019	-0.095	0.204
0.544	0.518	87	0.816	0.117	0.158	0.017	-0.026	0.088
0.597	0.545	40	0.816	-0.522	0.211	0.033	-0.052	0.138
0.647	0.592	33	0.850	-0.255	0.209	0.036	-0.055	0.147
0.691	0.580	14	0.740	0.330	0.106	0.028	-0.111	0.238
0.745	0.706	7	0.803	0.544	0.089	0.031	-0.039	0.119
0.793	0.766	5	0.900	0.630	0.119	0.049	-0.026	0.129
0.842	0.753	4	0.808	0.660	0.064	0.032	-0.089	0.200

Table 4.9: Bin analysis of shear exponents measured by RSD between 135 m and 100 m against cup anemometer measurements between 135 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3.3 Accuracy of RSD in Terms of Wind Shear between 120 m and 100 m

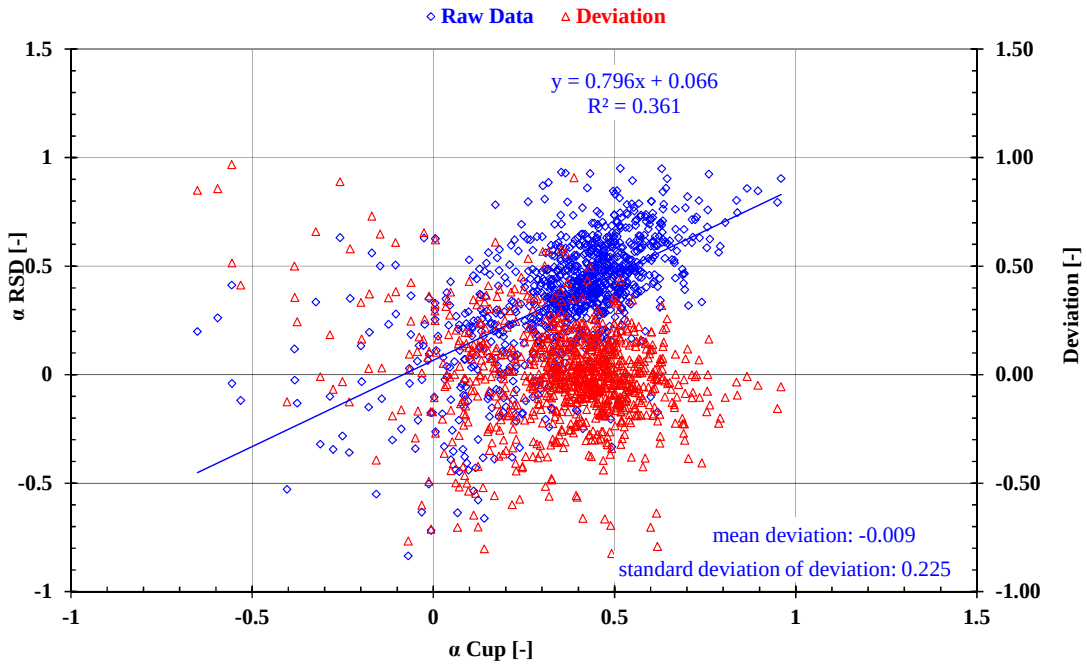

Figure 4.21: Scatter plot of shear exponents as measured by RSD between120 m and 100 m height against cup anemometer measurements between 120.3 m and 100.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

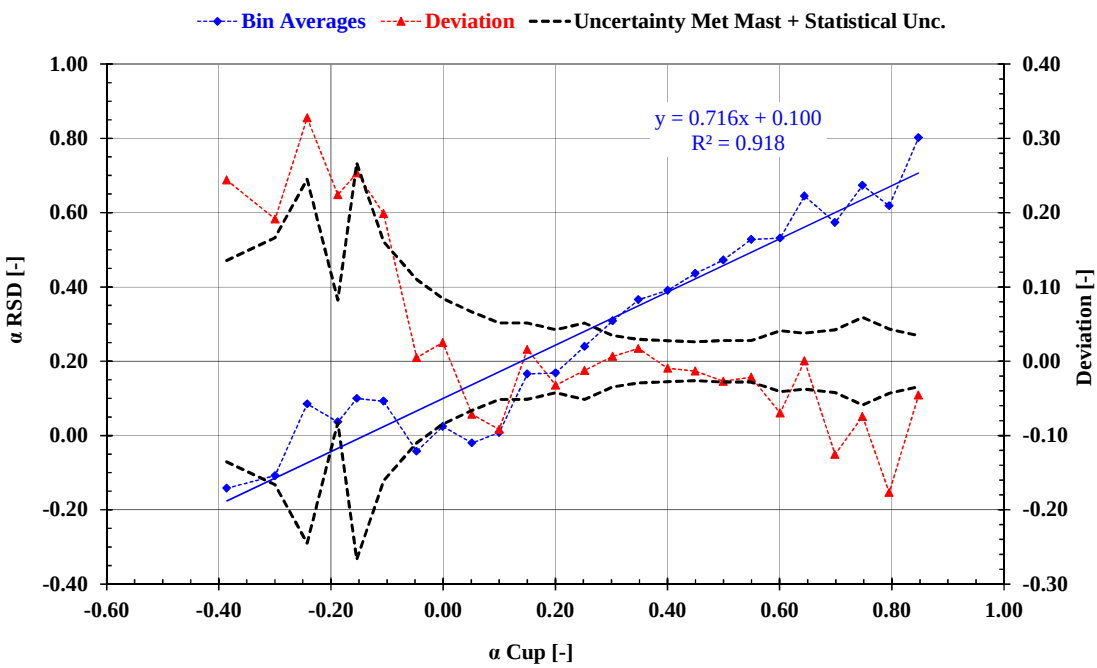

Figure 4.22: Bin analysis of shear exponents measured by RSD between 120 m and 100 m against cup anemometer measurements between 120.3 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.386	-0.142	4	0.118	-0.528	0.277	0.134	0.244	0.558
-0.299	-0.108	4	0.335	-0.345	0.315	0.165	0.191	0.507
-0.242	0.085	4	0.631	-0.359	0.484	0.244	0.328	0.818
-0.188	0.036	4	0.195	-0.150	0.157	0.079	0.224	0.477
-0.154	0.099	4	0.560	-0.551	0.530	0.266	0.253	0.736
-0.106	0.092	5	0.505	-0.302	0.353	0.159	0.199	0.511
-0.047	-0.042	13	0.629	-0.836	0.392	0.108	0.005	0.220
-0.001	0.025	17	0.627	-0.718	0.337	0.082	0.025	0.177
0.051	-0.020	24	0.428	-0.637	0.302	0.062	-0.072	0.195
0.100	0.008	37	0.529	-0.578	0.283	0.047	-0.092	0.211
0.150	0.166	38	0.783	-0.662	0.284	0.046	0.016	0.107
0.201	0.168	43	0.620	-0.382	0.237	0.036	-0.032	0.107
0.252	0.240	37	0.797	-0.336	0.286	0.046	-0.012	0.106
0.302	0.308	69	0.885	-0.242	0.223	0.027	0.006	0.071
0.348	0.366	105	0.932	-0.158	0.197	0.019	0.017	0.068
0.400	0.391	123	1.296	-0.249	0.181	0.016	-0.009	0.058
0.450	0.436	146	0.926	-0.192	0.165	0.014	-0.013	0.059
0.500	0.473	119	0.951	-0.333	0.186	0.017	-0.027	0.078
0.549	0.528	72	0.894	0.167	0.145	0.017	-0.021	0.070
0.601	0.531	43	0.799	-0.173	0.223	0.034	-0.070	0.162
0.644	0.645	27	0.949	0.310	0.154	0.030	0.001	0.075
0.699	0.573	16	0.820	0.318	0.147	0.036	-0.125	0.265
0.748	0.674	9	0.924	0.334	0.165	0.054	-0.074	0.190
0.795	0.618	3	0.701	0.563	0.073	0.037	-0.177	0.364
0.848	0.802	3	0.858	0.746	0.056	0.025	-0.046	0.114

Table 4.10: Bin analysis of shear exponents measured by RSD between 120 m and 100 m against cup anemometer measurements between 120.3 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3.4 Accuracy of RSD in Terms of Wind Shear between 100 m and 80 m

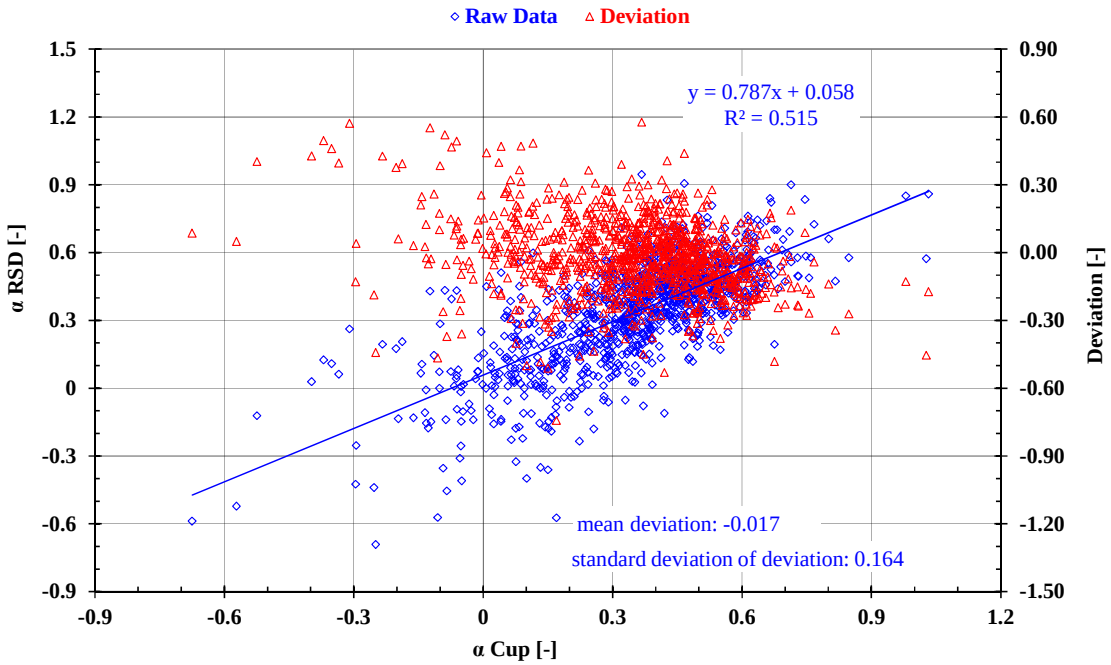

Figure 4.23: Scatter plot of shear exponents as measured by RSD between 100 m and 80 m height against cup anemometer measurements between 100.3 m and 82.2 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

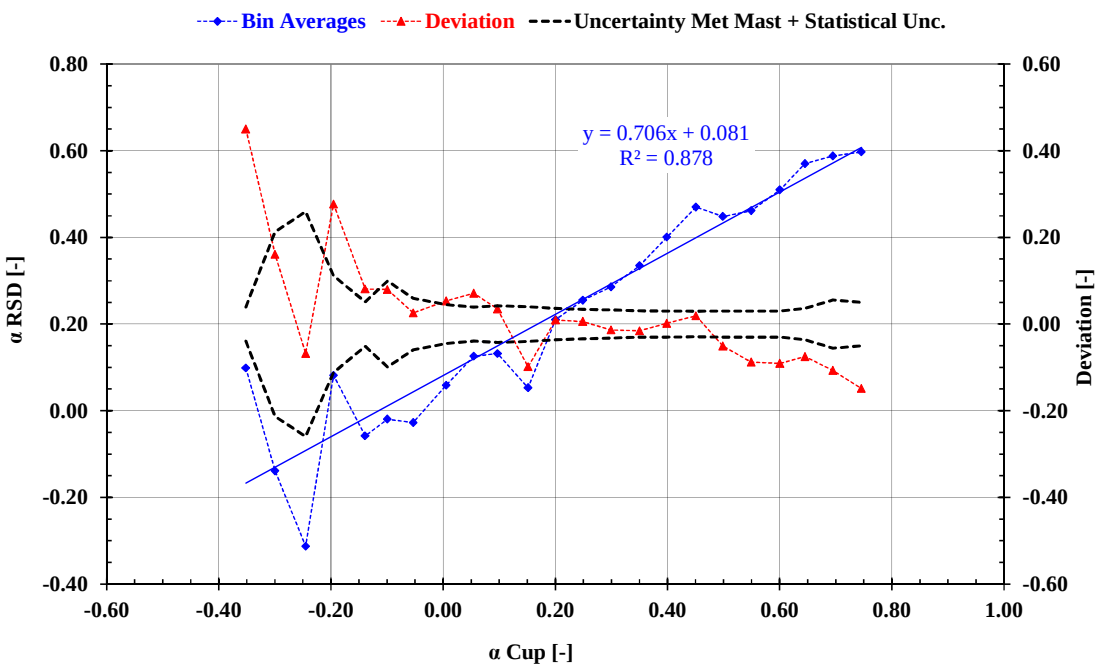

Figure 4.24: Bin analysis of shear exponents measured by RSD between 100 m and 80 m against cup anemometer measurements between 100.3 m and 82.2 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.352	0.099	3	0.125	0.062	0.033	0.029	0.450	0.904
-0.300	-0.139	3	0.262	-0.425	0.358	0.211	0.161	0.534
-0.245	-0.313	3	0.194	-0.692	0.456	0.258	-0.068	0.536
-0.195	0.082	3	0.206	-0.135	0.189	0.108	0.277	0.597
-0.139	-0.058	7	0.106	-0.177	0.113	0.044	0.081	0.192
-0.099	-0.019	12	0.433	-0.572	0.328	0.095	0.080	0.255
-0.053	-0.028	17	0.432	-0.410	0.213	0.053	0.026	0.130
0.005	0.059	18	0.450	-0.158	0.150	0.036	0.053	0.140
0.055	0.126	34	0.512	-0.228	0.165	0.028	0.071	0.162
0.097	0.132	43	0.599	-0.399	0.214	0.032	0.035	0.110
0.151	0.053	46	0.437	-0.573	0.200	0.030	-0.099	0.213
0.201	0.210	49	0.499	-0.235	0.164	0.024	0.009	0.074
0.249	0.255	61	0.609	-0.180	0.161	0.020	0.006	0.069
0.299	0.286	81	0.711	-0.062	0.164	0.018	-0.014	0.071
0.350	0.335	122	0.945	-0.079	0.150	0.013	-0.016	0.068
0.399	0.400	112	0.735	-0.111	0.140	0.013	0.002	0.061
0.451	0.470	125	0.905	0.191	0.124	0.011	0.019	0.070
0.499	0.448	106	0.761	0.117	0.134	0.013	-0.051	0.118
0.549	0.462	75	0.808	0.170	0.113	0.013	-0.088	0.185
0.600	0.510	64	0.761	0.303	0.105	0.013	-0.091	0.191
0.645	0.570	26	0.839	0.421	0.124	0.024	-0.075	0.167
0.695	0.588	12	0.900	0.194	0.174	0.049	-0.107	0.242
0.746	0.597	8	0.834	0.488	0.123	0.042	-0.149	0.313

Table 4.11: Bin analysis of shear exponents measured by RSD between 100 m and 80 m against cup anemometer measurements between 100.3 m and 82.2 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3.5 Accuracy of RSD in Terms of Wind Shear between 80 m and 60 m

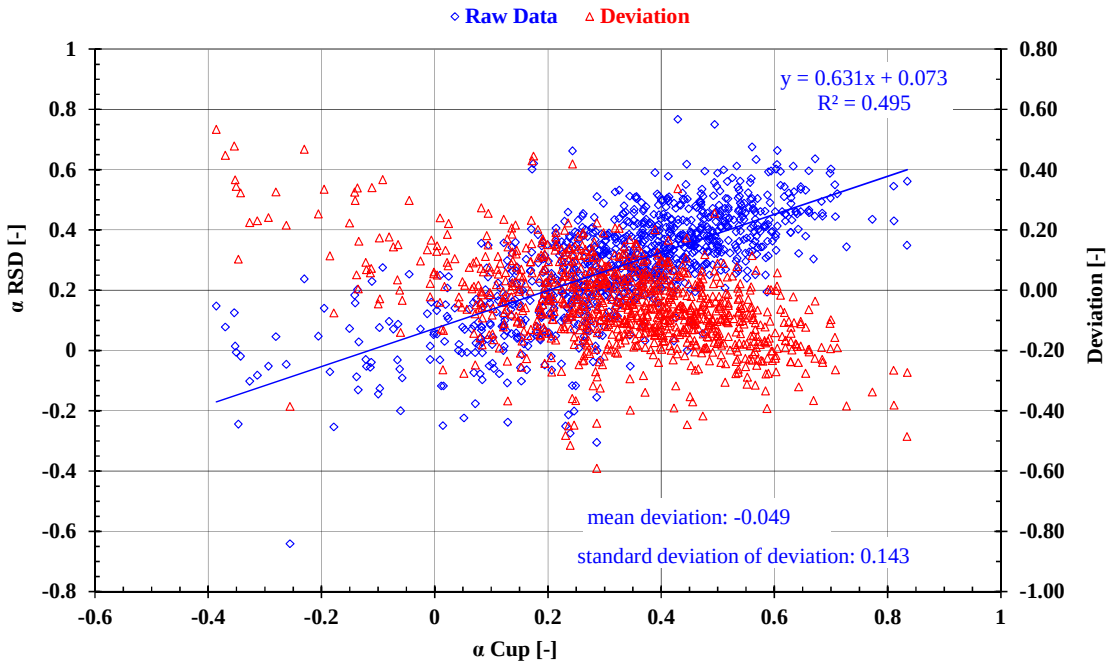

Figure 4.25: Scatter plot of shear exponents as measured by RSD between 80 m and 60 m height against cup anemometer measurements between 82.2 m and 60.4 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

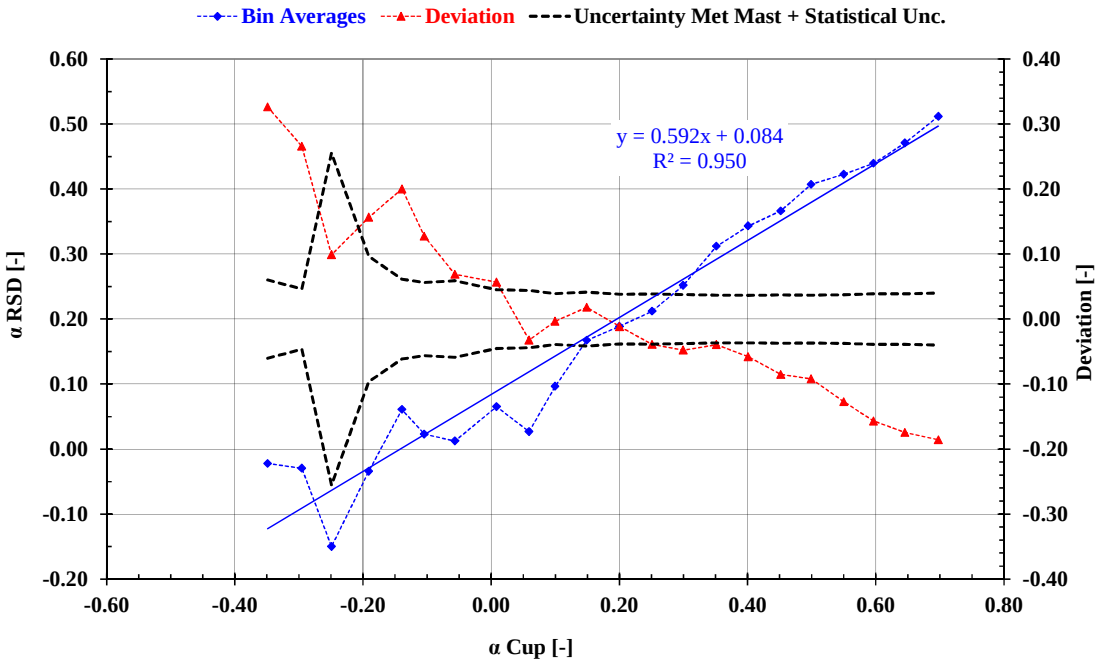

Figure 4.26: Bin analysis of shear exponents measured by RSD between 80 m and 60 m against cup anemometer measurements between 82.2 m and 60.4 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.349	-0.022	7	0.125	-0.244	0.122	0.049	0.327	0.664
-0.295	-0.030	3	0.046	-0.082	0.067	0.030	0.266	0.540
-0.249	-0.150	3	0.238	-0.641	0.449	0.253	0.099	0.548
-0.191	-0.034	4	0.140	-0.254	0.170	0.090	0.157	0.368
-0.139	0.061	7	0.202	-0.131	0.132	0.050	0.200	0.419
-0.104	0.023	10	0.276	-0.145	0.143	0.044	0.127	0.278
-0.056	0.012	8	0.253	-0.200	0.138	0.047	0.069	0.181
0.008	0.065	20	0.249	-0.250	0.128	0.029	0.057	0.145
0.059	0.027	17	0.170	-0.224	0.109	0.027	-0.032	0.109
0.100	0.096	43	0.357	-0.097	0.114	0.017	-0.003	0.079
0.149	0.167	51	0.620	-0.238	0.161	0.022	0.018	0.091
0.200	0.189	62	0.406	-0.065	0.121	0.015	-0.012	0.080
0.251	0.212	96	0.662	-0.275	0.158	0.016	-0.039	0.110
0.300	0.252	94	0.526	-0.305	0.137	0.014	-0.048	0.122
0.351	0.312	108	0.532	-0.052	0.111	0.011	-0.039	0.108
0.401	0.343	105	0.590	0.032	0.099	0.010	-0.058	0.137
0.452	0.367	95	0.767	0.000	0.118	0.012	-0.085	0.186
0.499	0.407	73	0.750	0.208	0.094	0.011	-0.092	0.198
0.550	0.423	63	0.675	0.240	0.101	0.013	-0.127	0.265
0.597	0.440	38	0.664	0.195	0.105	0.016	-0.157	0.323
0.645	0.471	26	0.636	0.304	0.080	0.016	-0.174	0.357
0.698	0.512	9	0.602	0.444	0.059	0.019	-0.186	0.380

Table 4.12: Bin analysis of shear exponents measured by RSD between 80 m and 60 m against cup anemometer measurements between 82.2 m and 60.4 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.3.6 Accuracy of RSD in Terms of Wind Shear between 60 m and 40 m

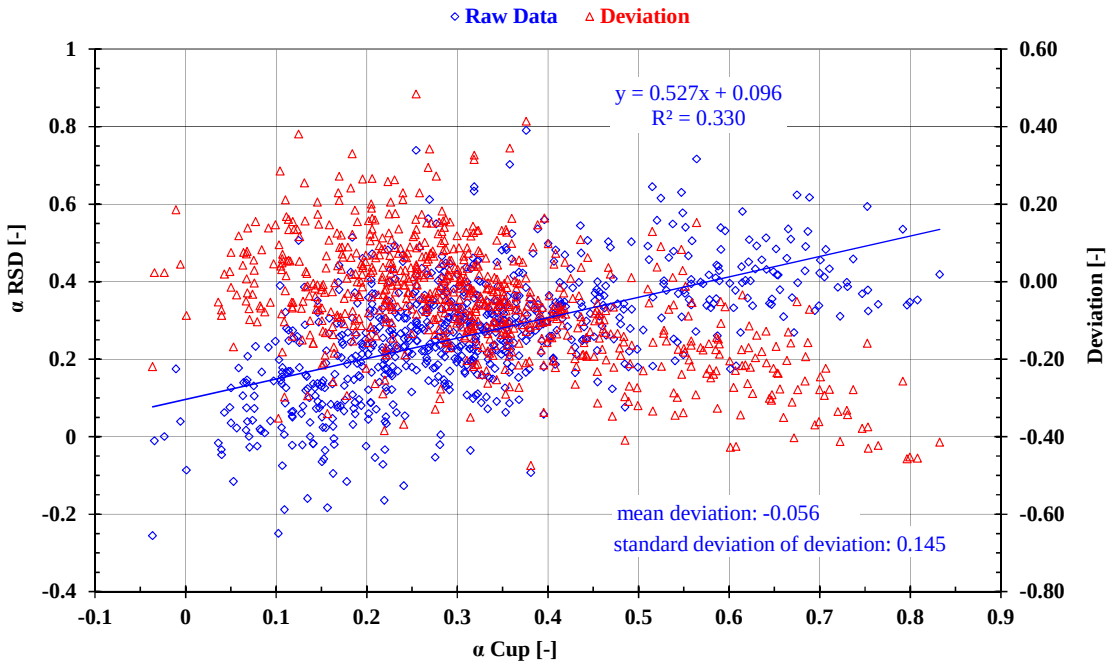

Figure 4.27: Scatter plot of shear exponents as measured by RSD between 60 m and 40 m height against cup anemometer measurements between 60.4 m and 40.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

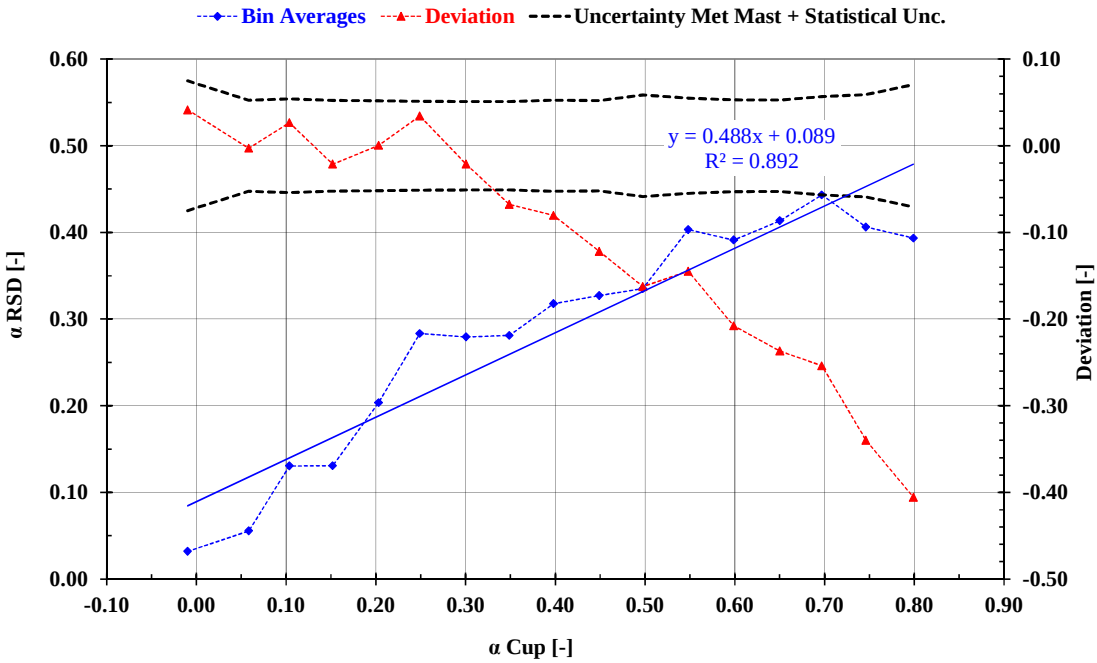

Figure 4.28: Bin analysis of shear exponents measured by RSD between 60 m and 40 m against cup anemometer measurements between 60.4 m and 40.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

α (Reference)	α (RSD)	number of data sets	α (RSD) max	α (RSD) min	α (RSD) std	α (RSD) std/sqrt(n)	α (RSD) - α (Reference)	uncertainty (*k* =2) α (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.010	0.032	4	0.175	-0.087	0.109	0.056	0.041	0.171
0.058	0.055	21	0.207	-0.116	0.082	0.017	-0.003	0.105
0.104	0.130	43	0.506	-0.250	0.141	0.021	0.027	0.121
0.152	0.131	66	0.442	-0.184	0.135	0.016	-0.021	0.113
0.203	0.203	89	0.514	-0.165	0.136	0.014	0.000	0.104
0.249	0.283	94	0.739	-0.127	0.119	0.012	0.034	0.123
0.301	0.279	120	0.645	-0.053	0.121	0.011	-0.021	0.111
0.349	0.281	95	0.702	0.063	0.107	0.011	-0.068	0.169
0.398	0.318	56	0.790	-0.093	0.126	0.017	-0.080	0.192
0.449	0.327	42	0.544	0.123	0.097	0.015	-0.122	0.265
0.498	0.335	22	0.645	0.076	0.152	0.031	-0.163	0.346
0.548	0.403	28	0.717	0.195	0.124	0.023	-0.145	0.310
0.599	0.391	29	0.581	0.175	0.095	0.018	-0.208	0.429
0.650	0.413	20	0.536	0.269	0.074	0.017	-0.237	0.485
0.697	0.443	15	0.623	0.311	0.094	0.027	-0.254	0.520
0.746	0.406	8	0.594	0.324	0.086	0.031	-0.340	0.690
0.799	0.393	4	0.535	0.339	0.095	0.050	-0.406	0.823

Table 4.13: Bin analysis of shear exponents measured by RSD between 60 m and 40 m against cup anemometer measurements between 60.4 m and 40.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4 Accuracy of the RSD in Terms of Wind Direction

The wind direction as measured by the RSD and by the met mast is compared for measurement heights of 135 m , 130 m, 120 m, 100 m, 80 m, 60 m, 40 m in the following sub chapter. The following conclusions can be drawn:

- The wind direction as measured by the RSD and by the vane correlates good with squared correlation coefficient of 0.989 – 0.998. Hardly any outlier data is observed in the respective scatter plot, see Figure 4.29, Figure 4.31, Figure 4.33, Figure 4.35, Figure 4.37 and Figure 4.39.
- The RSD shows value of mean deviation of -2.98° to 0.66°.
- Overall, the wind direction measurement of the RSD is considered as good.

4.4.1 Wind Direction at 135 m Height

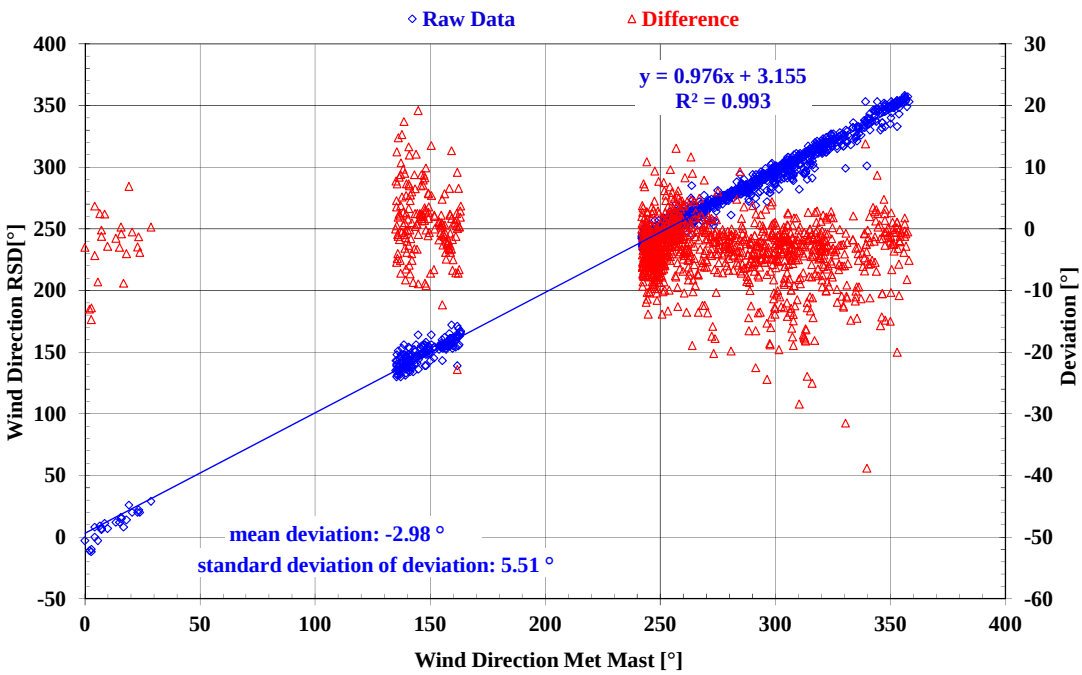

Figure 4.29: Scatter plot of wind direction as measured by RSD at 135 m height above ground against vane readings at 129 m measurement height.

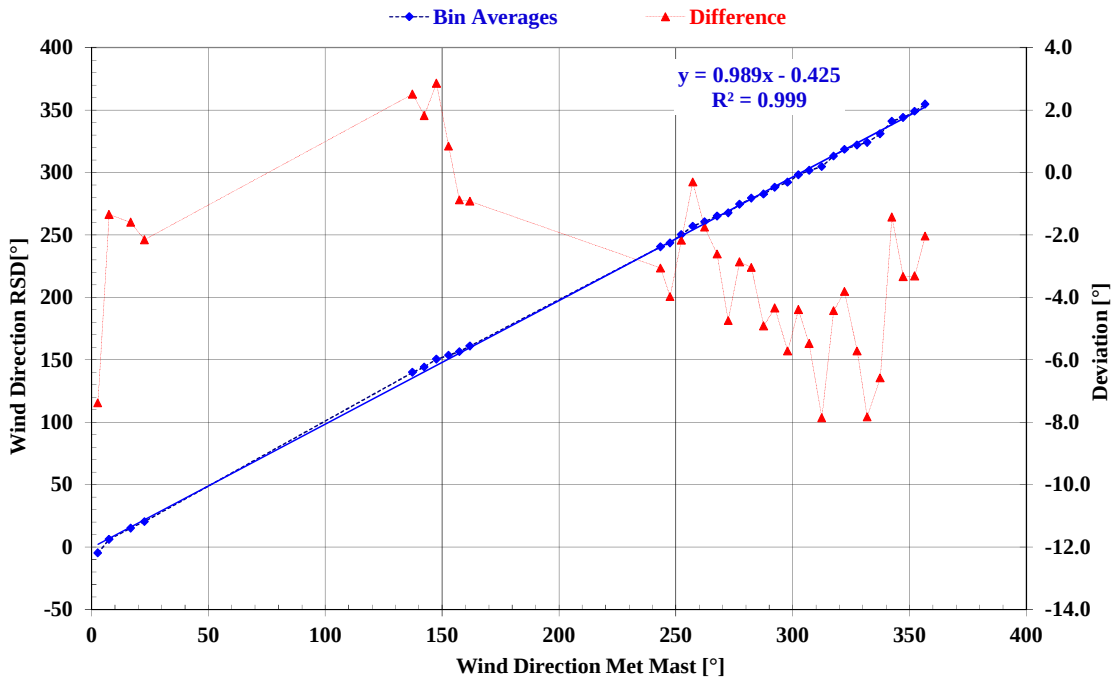

Figure 4.30: Bin analysis of wind direction as measured by RSD at 135 m height above ground against vane readings at 129 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
2.7	-4.7	6	8	-12	7.840	3.201	-7.38	8.61	17.09
7.5	6.2	6	11	-3	4.834	1.973	-1.35	7.06	7.56
16.8	15.2	6	26	8	6.014	2.455	-1.60	7.53	8.18
22.7	20.5	4	22	20	1.000	0.500	-2.15	6.39	7.71
137.4	139.9	43	156	130	6.376	0.972	2.51	6.50	8.21
142.4	144.2	33	164	134	6.784	1.181	1.82	6.62	7.56
147.6	150.5	30	158	139	4.345	0.793	2.86	6.41	8.59
152.8	153.6	14	164	143	5.002	1.337	0.84	6.75	6.96
157.4	156.5	33	172	143	4.644	0.808	-0.88	6.39	6.63
161.9	161.0	20	171	139	6.882	1.539	-0.93	6.89	7.13
243.5	240.5	100	255	231	3.991	0.399	-3.06	6.26	8.76
247.5	243.6	154	257	235	3.673	0.296	-3.98	6.24	10.11
252.4	250.2	95	264	237	4.749	0.487	-2.17	6.27	7.63
257.3	257.0	82	270	245	3.801	0.420	-0.31	6.27	6.30
262.3	260.6	48	285	245	6.700	0.967	-1.76	6.49	7.38
267.7	265.1	33	277	253	5.276	0.918	-2.61	6.45	8.31
272.4	267.7	30	276	253	6.277	1.146	-4.75	6.62	11.57
277.3	274.5	32	281	268	2.805	0.496	-2.87	6.28	8.50
282.3	279.3	31	294	261	4.934	0.886	-3.04	6.41	8.84
287.6	282.7	33	290	272	4.127	0.718	-4.91	6.40	11.73
292.4	288.0	41	296	269	5.380	0.840	-4.34	6.41	10.79
297.9	292.2	45	303	272	6.576	0.980	-5.72	6.50	13.16
302.5	298.1	47	304	282	4.398	0.641	-4.39	6.33	10.83
307.1	301.6	55	311	289	5.435	0.733	-5.48	6.38	12.69
312.5	304.6	35	317	282	7.919	1.339	-7.86	6.75	17.11
317.5	313.1	44	321	291	6.046	0.911	-4.43	6.42	10.94
322.2	318.4	40	327	311	3.967	0.627	-3.82	6.31	9.91
327.6	321.9	18	328	315	3.864	0.911	-5.72	6.53	13.17
331.9	324.1	14	336	299	8.940	2.389	-7.83	7.67	17.44
337.5	330.9	21	353	301	9.633	2.102	-6.58	7.43	15.12
342.5	341.1	20	353	330	5.482	1.226	-1.43	6.55	7.14
347.3	344.0	19	352	330	6.912	1.586	-3.34	6.87	9.59
352.2	348.9	27	354	333	5.546	1.067	-3.32	6.53	9.30
356.7	354.7	10	358	349	2.751	0.870	-2.04	6.50	7.67

Table 4.14 Bin analysis of wind direction as measured by RSD at 135 m height above ground against vane readings at 129 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4.2 Wind Direction at 120 m Height

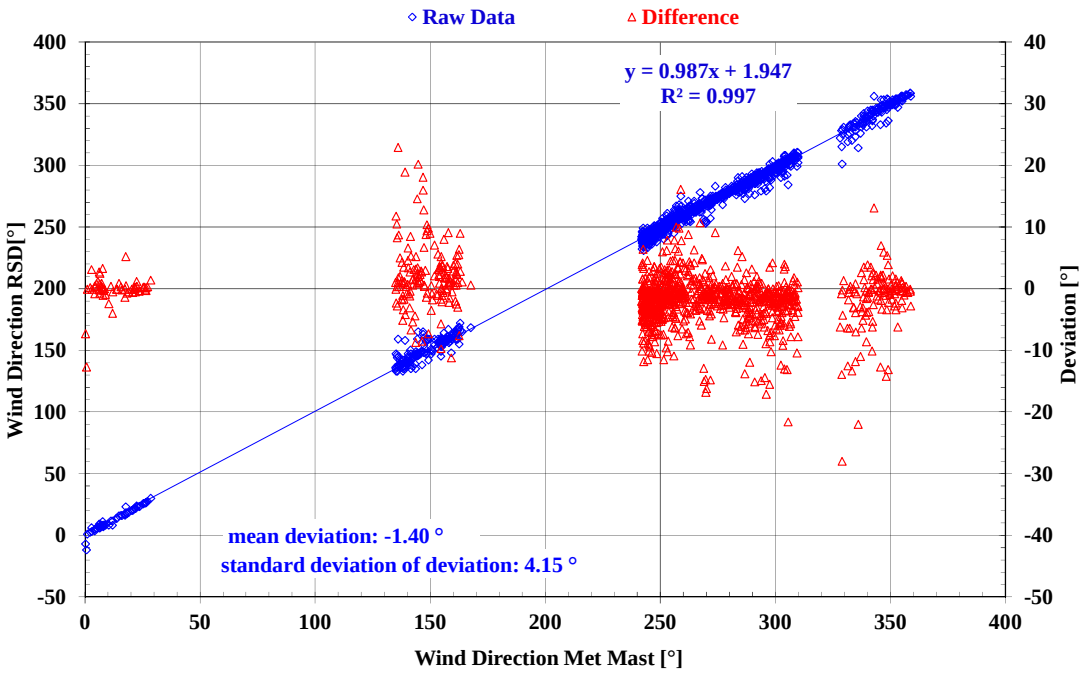

Figure 4.31: Scatter plot of wind direction as measured by RSD at 120 mheight above ground against vane readings at 118.3 m measurement height.

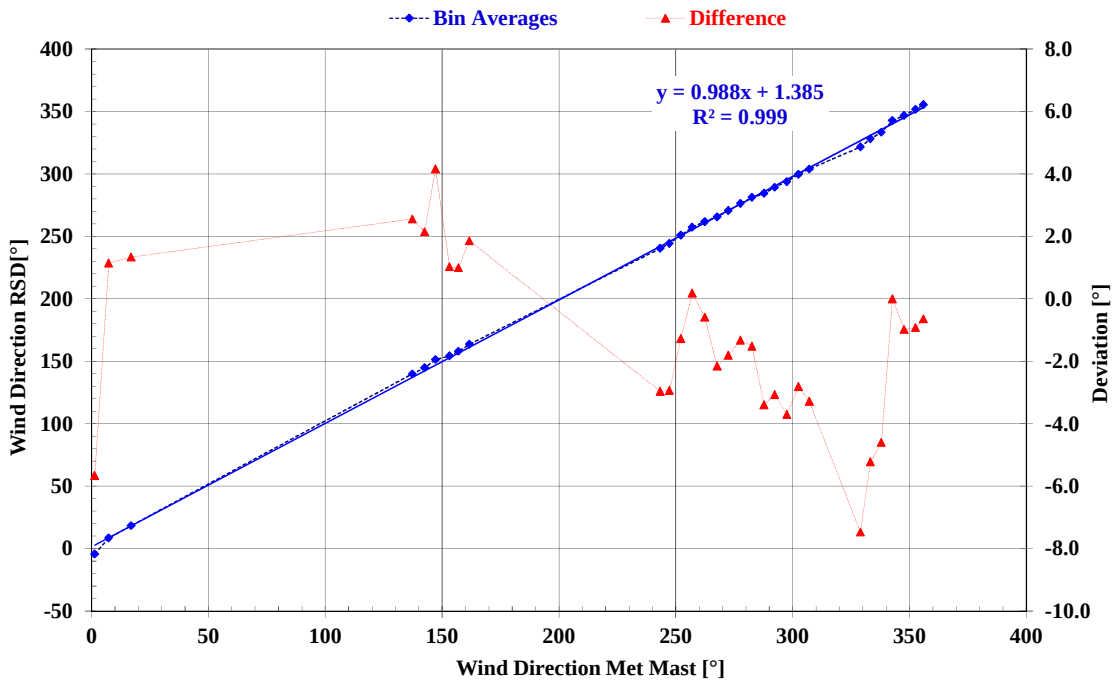

Figure 4.32: Bin analysis of wind direction as measured by RSD at 120 mheight above ground against vane readings at 118.3 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
1.3	-4.3	3	6	-12	9.292	5.364	-5.66	11.16	15.90
7.4	8.5	4	11	6	2.082	1.041	1.14	6.54	6.93
17.0	18.3	3	23	16	4.041	2.333	1.34	7.37	7.84
137.3	139.8	31	159	133	6.197	1.113	2.56	6.62	8.37
142.6	144.7	28	165	135	6.388	1.207	2.15	6.60	7.87
147.2	151.4	22	165	138	6.980	1.488	4.16	6.84	10.77
153.2	154.2	19	160	145	4.442	1.019	1.03	6.54	6.86
157.0	158.0	27	167	148	3.546	0.682	1.00	6.37	6.67
161.6	163.5	20	172	155	3.940	0.881	1.86	6.43	7.43
243.4	240.4	100	249	231	3.175	0.318	-2.97	6.24	8.61
247.3	244.4	131	253	235	3.204	0.280	-2.93	6.23	8.56
252.1	250.9	84	261	240	4.056	0.443	-1.28	6.26	6.76
257.1	257.3	72	275	245	4.859	0.573	0.18	6.30	6.31
262.4	261.8	34	271	254	4.802	0.824	-0.59	6.38	6.49
267.7	265.6	29	278	253	5.895	1.095	-2.16	6.62	7.90
272.4	270.6	31	283	254	5.232	0.940	-1.80	6.43	7.38
277.7	276.4	27	282	268	2.720	0.523	-1.32	6.28	6.81
282.6	281.1	33	290	276	2.930	0.510	-1.51	6.28	6.97
287.8	284.4	37	293	273	4.106	0.675	-3.40	6.32	9.28
292.3	289.2	33	295	276	4.287	0.746	-3.07	6.37	8.84
297.5	293.8	48	303	279	4.870	0.703	-3.70	6.34	9.75
302.5	299.7	50	308	290	3.706	0.524	-2.81	6.29	8.43
307.2	303.9	37	310	284	4.808	0.790	-3.29	6.38	9.16
329.0	321.6	7	331	301	10.518	3.975	-7.47	10.02	17.99
333.3	328.1	12	334	319	5.316	1.535	-5.22	6.84	12.48
338.0	333.4	16	342	314	6.732	1.683	-4.61	6.91	11.51
342.7	342.7	16	356	332	5.486	1.371	0.00	6.74	6.74
347.7	346.8	24	354	333	5.574	1.138	-0.98	6.60	6.89
352.6	351.7	15	356	347	2.498	0.645	-0.92	6.32	6.58
356.0	355.4	8	357	352	1.506	0.532	-0.64	6.32	6.45

Table 4.15 Bin analysis of wind direction as measured by RSD at 120 mheight above ground against vane readings at 118.3 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4.3 Wind Direction at 100 m Height

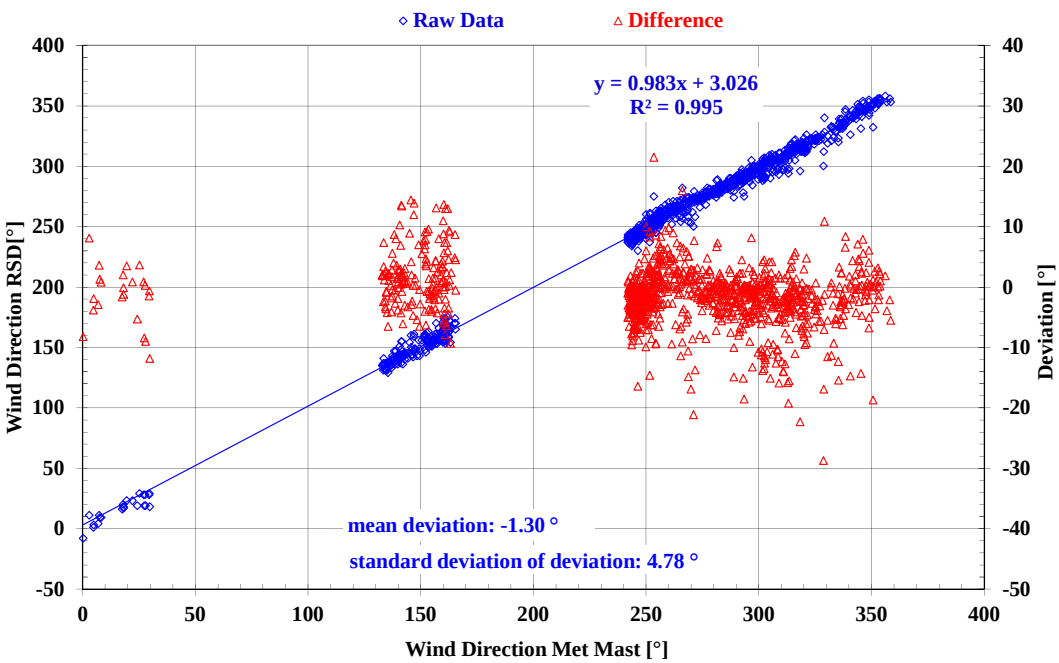

Figure 4.33: Scatter plot of wind direction as measured by RSD at 100 m height above ground against vane readings at 98.2 m measurement height.

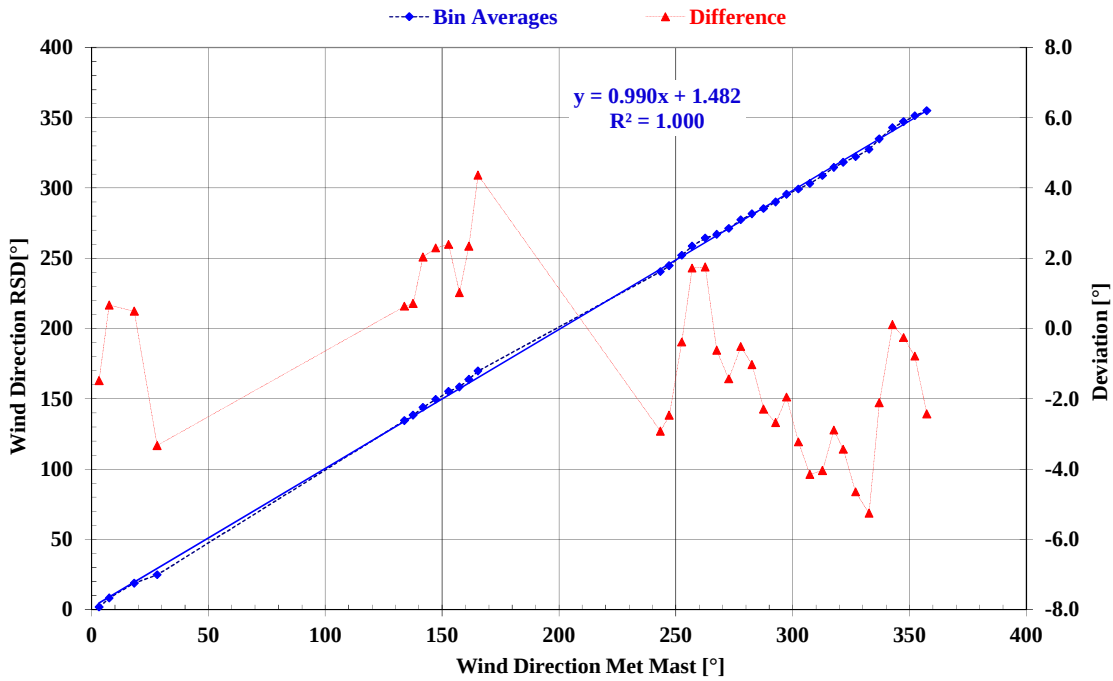

Figure 4.34: Bin analysis of wind direction as measured by RSD at 100 m height above ground against vane readings at 98.2 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
3.2	1.8	4	11	-8	7.805	3.902	-1.48	9.28	9.74
7.6	8.3	4	11	4	2.986	1.493	0.67	6.77	6.90
18.3	18.8	5	23	16	2.775	1.241	0.49	6.51	6.58
28.1	24.8	8	29	18	5.064	1.790	-3.33	7.37	9.94
133.9	134.6	14	141	131	2.793	0.747	0.63	6.42	6.54
137.6	138.3	24	147	129	4.310	0.880	0.71	6.40	6.56
141.9	143.9	28	155	136	4.280	0.809	2.04	6.44	7.62
147.3	149.6	17	161	142	6.256	1.517	2.29	7.01	8.38
152.8	155.2	23	163	146	4.421	0.922	2.40	6.54	8.11
157.4	158.4	32	170	151	4.318	0.763	1.02	6.35	6.67
161.5	163.8	29	175	153	6.612	1.228	2.35	6.68	8.17
165.4	169.8	4	174	165	3.686	1.843	4.37	7.27	11.37
243.4	240.5	69	246	234	2.599	0.313	-2.92	6.25	8.56
247.2	244.7	125	254	230	3.294	0.295	-2.47	6.23	7.95
252.6	252.2	83	275	237	5.108	0.561	-0.39	6.30	6.35
257.0	258.7	48	268	249	3.892	0.562	1.72	6.30	7.18
262.6	264.4	33	271	252	3.847	0.670	1.75	6.37	7.27
267.6	266.9	34	282	253	6.615	1.134	-0.62	6.62	6.74
272.7	271.2	30	279	250	5.685	1.038	-1.43	6.52	7.12
277.9	277.3	32	282	268	2.847	0.503	-0.51	6.28	6.36
282.7	281.6	42	289	274	3.099	0.478	-1.03	6.27	6.60
287.6	285.3	43	291	274	3.504	0.534	-2.29	6.29	7.78
292.8	290.1	43	297	275	4.369	0.666	-2.68	6.35	8.31
297.5	295.5	51	305	284	3.557	0.498	-1.95	6.28	7.40
302.5	299.3	49	309	288	5.489	0.784	-3.23	6.39	9.08
307.4	303.2	36	311	290	5.060	0.843	-4.15	6.44	10.51
312.8	308.8	45	319	294	5.959	0.888	-4.04	6.42	10.32
317.6	314.7	38	322	296	4.458	0.723	-2.89	6.39	8.62
321.7	318.3	22	326	311	4.049	0.863	-3.44	6.41	9.40
326.9	322.3	18	340	300	7.630	1.798	-4.65	7.23	11.79
332.7	327.5	11	333	319	4.634	1.397	-5.26	6.72	12.48
337.1	335.0	24	347	320	5.614	1.146	-2.11	6.54	7.79
342.8	342.9	20	351	326	5.241	1.172	0.11	6.53	6.53
347.5	347.2	21	355	331	5.166	1.127	-0.26	6.57	6.59
352.3	351.5	16	356	332	5.692	1.423	-0.79	6.72	6.90
357.4	355.0	4	358	353	2.449	1.225	-2.43	6.98	8.51

Table 4.16 Bin analysis of wind direction as measured by RSD at 120 m height above ground against vane readings at 98.2 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4.4 Wind Direction at 80 m Height

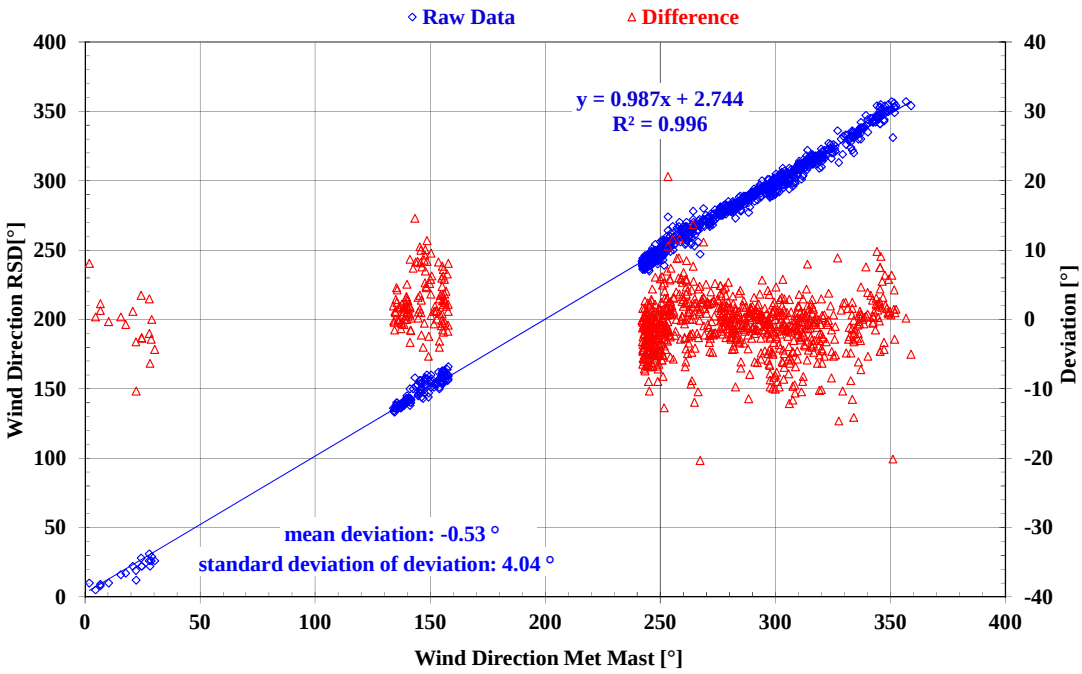

Figure 4.35: Scatter plot of wind direction as measured by RSD at 80 m height above ground against vane readings at 80.1 m measurement height.

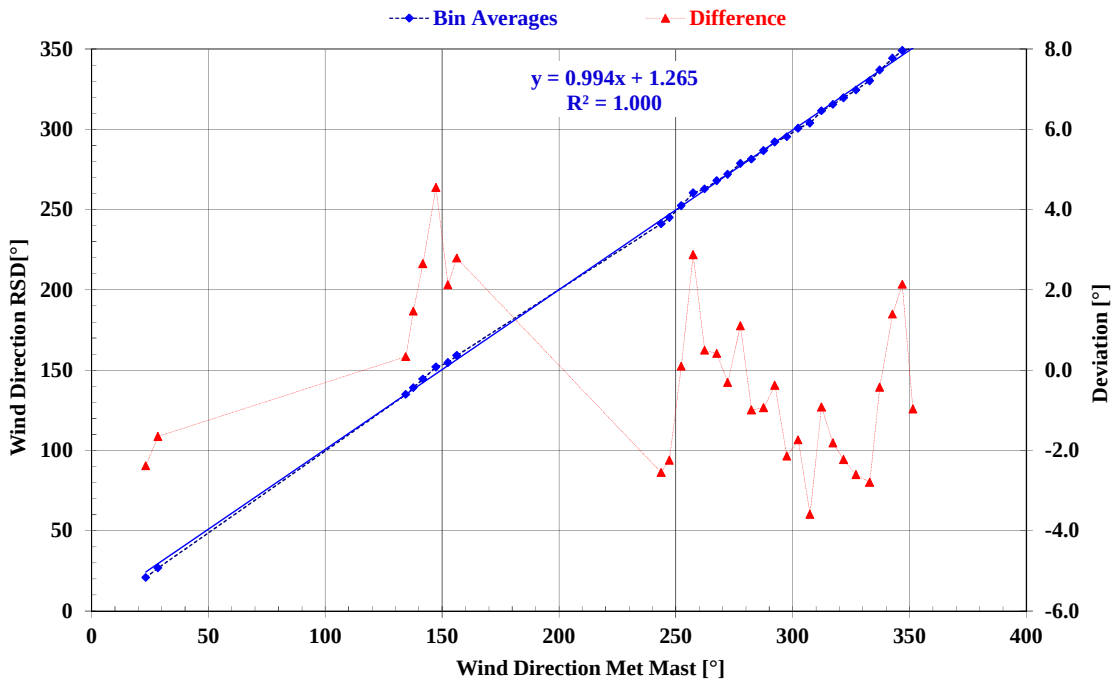

Figure 4.36: Bin analysis of wind direction as measured by RSD at 80 m height above ground against vane readings at 80.1 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
23.2	20.8	6	28	12	5.231	2.136	-2.38	7.31	8.72
28.4	26.8	5	31	22	3.421	1.530	-1.65	6.93	7.68
134.5	134.8	6	136	133	1.329	0.543	0.34	6.30	6.34
137.7	139.1	25	145	136	2.369	0.474	1.47	6.25	6.90
141.8	144.5	24	158	138	4.917	1.004	2.65	6.43	8.33
147.4	151.9	23	160	143	5.017	1.046	4.55	6.55	11.21
152.5	154.7	18	162	150	3.218	0.758	2.13	6.44	7.72
156.3	159.1	27	166	154	3.100	0.597	2.79	6.32	8.43
243.7	241.2	81	247	236	2.623	0.291	-2.55	6.24	8.05
247.3	245.0	100	254	235	3.096	0.310	-2.24	6.24	7.68
252.4	252.5	76	274	239	5.003	0.574	0.10	6.30	6.30
257.5	260.3	27	270	250	4.756	0.915	2.87	6.42	8.62
262.4	262.9	42	278	253	5.243	0.809	0.50	6.41	6.49
267.5	268.0	25	280	247	6.321	1.264	0.41	6.63	6.68
272.2	271.9	27	279	267	2.854	0.549	-0.30	6.30	6.33
277.6	278.8	45	285	275	2.207	0.329	1.11	6.24	6.62
282.4	281.4	46	289	273	2.841	0.419	-0.99	6.25	6.56
287.6	286.7	35	291	277	3.660	0.619	-0.94	6.30	6.58
292.4	292.1	37	300	285	2.999	0.493	-0.38	6.27	6.31
297.5	295.4	46	302	288	3.531	0.521	-2.14	6.30	7.61
302.4	300.7	44	309	290	4.420	0.666	-1.73	6.32	7.21
307.4	303.8	36	310	294	4.088	0.681	-3.59	6.34	9.58
312.4	311.5	42	322	301	3.814	0.589	-0.92	6.30	6.56
317.3	315.5	28	319	309	2.687	0.508	-1.81	6.31	7.27
321.8	319.6	21	327	310	4.094	0.893	-2.23	6.41	7.81
327.1	324.5	10	336	313	6.819	2.156	-2.60	7.52	9.14
333.0	330.2	19	336	320	4.417	1.013	-2.79	6.55	8.61
337.3	336.8	18	347	330	4.062	0.957	-0.42	6.41	6.47
342.8	344.2	17	354	335	3.812	0.924	1.40	6.39	6.97
346.9	349.0	21	355	341	4.236	0.924	2.14	6.46	7.74
351.5	350.5	8	357	331	8.281	2.928	-0.97	8.50	8.71

Table 4.17 Bin analysis of wind direction as measured by RSD at 80 m height above ground against vane readings at 80.1 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4.5 Wind Direction at 60 m Height

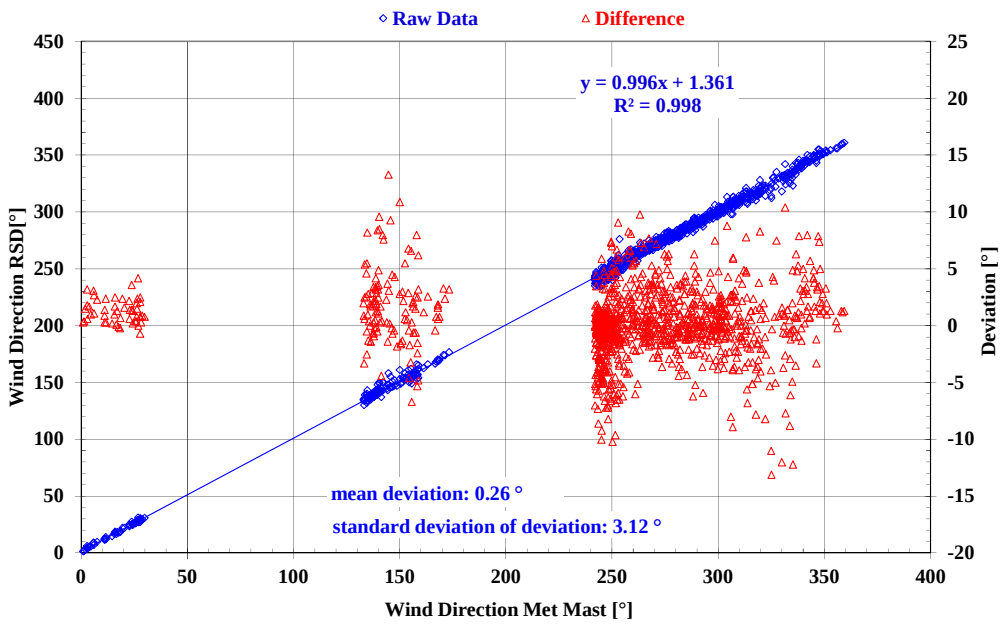

Figure 4.37: Scatter plot of wind direction as measured by RSD at 60 m height above ground against vane readings at 58.2 m measurement height.

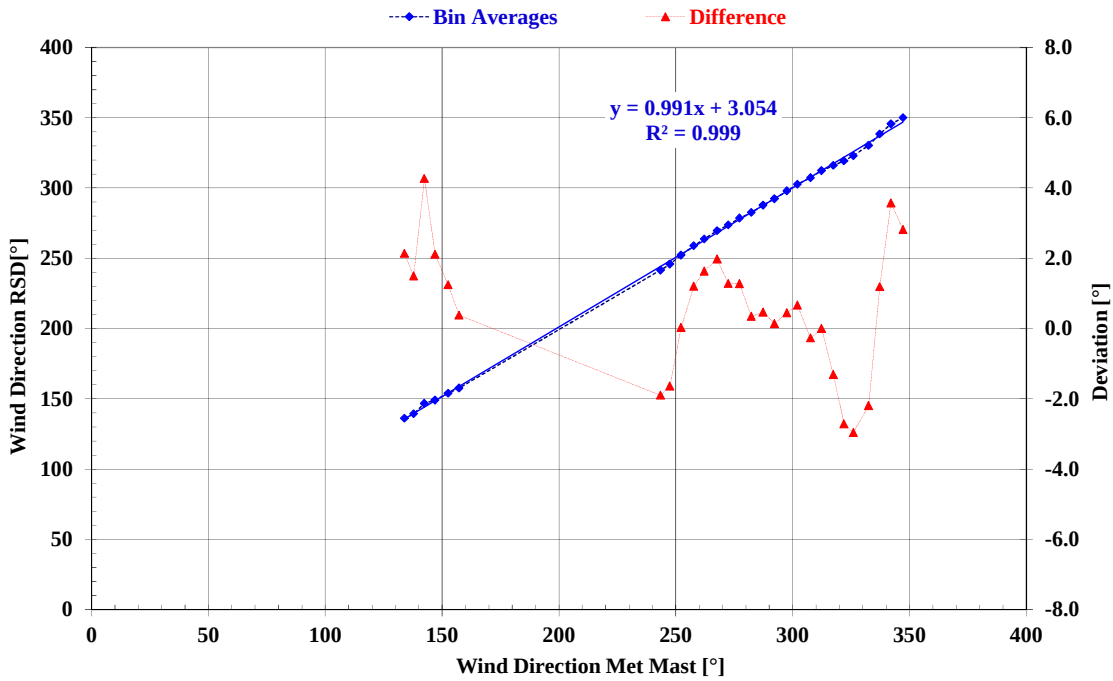

Figure 4.38: Bin analysis of wind direction as measured by RSD at 60 m height above ground against vane readings at 58.2 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
133.9	136.1	12	143	130	3.679	1.062	2.14	6.51	7.79
137.8	139.3	32	148	134	2.989	0.528	1.50	6.25	6.93
142.4	146.7	13	158	137	5.282	1.465	4.27	6.80	10.91
147.0	149.1	7	155	146	3.532	1.335	2.11	6.92	8.10
152.6	153.8	13	161	149	4.059	1.126	1.25	6.63	7.09
157.3	157.7	18	166	149	4.419	1.042	0.38	6.51	6.55
243.5	241.6	71	247	235	2.665	0.316	-1.90	6.24	7.31
247.4	245.8	90	257	235	4.295	0.453	-1.64	6.26	7.07
252.3	252.3	58	276	240	5.487	0.720	0.03	6.36	6.36
257.7	258.9	38	267	249	4.716	0.765	1.20	6.33	6.77
262.2	263.8	28	273	255	4.095	0.774	1.63	6.35	7.14
267.7	269.7	37	275	265	2.416	0.397	1.98	6.25	7.40
272.4	273.7	36	281	269	3.048	0.508	1.28	6.27	6.78
277.3	278.5	33	283	274	2.526	0.440	1.28	6.27	6.77
282.3	282.7	33	289	277	3.266	0.569	0.35	6.27	6.31
287.3	287.8	35	295	281	3.333	0.563	0.46	6.28	6.35
292.3	292.4	34	297	287	2.285	0.392	0.14	6.25	6.26
297.5	298.0	30	306	293	2.553	0.466	0.45	6.27	6.34
302.0	302.7	37	313	298	2.856	0.470	0.67	6.26	6.40
307.6	307.3	29	314	298	3.976	0.738	-0.27	6.36	6.38
312.4	312.4	21	321	307	3.735	0.815	0.00	6.41	6.41
317.4	316.1	22	328	310	4.023	0.858	-1.31	6.38	6.90
322.0	319.3	10	323	314	2.751	0.870	-2.71	6.47	8.44
326.0	323.0	6	335	312	8.944	3.651	-2.96	9.17	10.92
332.5	330.3	18	342	318	5.053	1.191	-2.19	6.62	7.94
337.3	338.5	19	346	323	5.015	1.151	1.19	6.53	6.95
342.1	345.7	12	350	341	2.871	0.829	3.58	6.33	9.56
347.2	350.1	16	355	343	3.172	0.793	2.82	6.37	8.51

Table 4.18 Bin analysis of wind direction as measured by RSD at 60 m height above ground against vane readings at 58.2 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.4.6 Wind Direction at 40 m Height

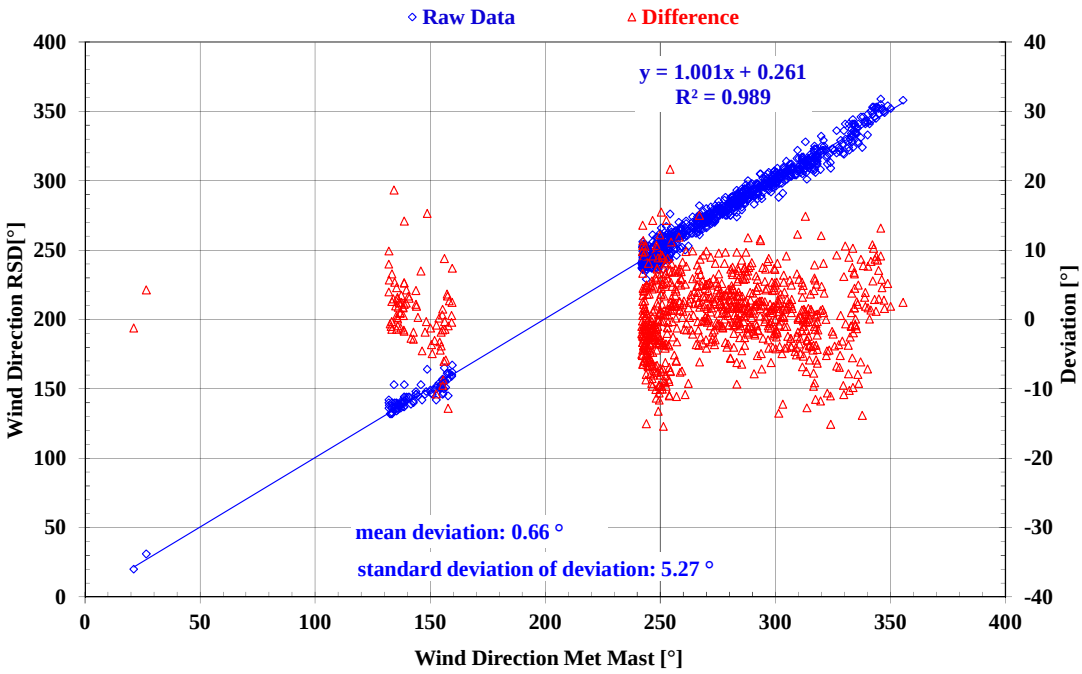

Figure 4.39: Scatter plot of wind direction as measured by RSD at 40 m height above ground against vane readings at 38.2 m measurement height.

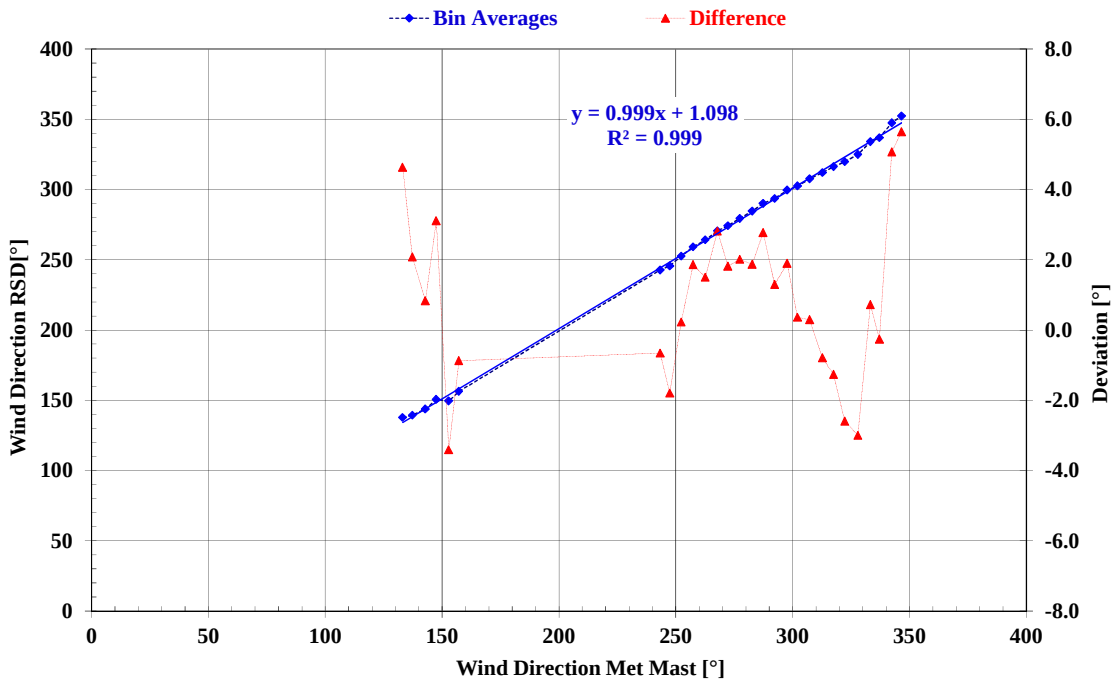

Figure 4.40: Bin analysis of wind direction as measured by RSD at 40 m height above ground against vane readings at 38.2 m measurement height.

Dir (Reference)	Dir (RSD)	number of data sets	Dir (RSD) max	Dir (RSD) min	Dir (RSD) std	Dir(RSD) std/sqrt(n)	Dir (RSD) - Dir (Reference)	uncertainty (*k* =2) (calibration)	uncertainty (k=2) Dir (RSD)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
133.1	137.8	13	153	132	5.732	1.590	4.63	6.93	11.57
137.3	139.4	27	153	134	3.824	0.736	2.08	6.33	7.57
142.8	143.7	9	148	139	3.041	1.014	0.84	6.47	6.68
147.5	150.6	5	164	142	8.473	3.789	3.11	9.49	11.35
152.9	149.5	11	154	142	3.446	1.039	-3.41	6.45	9.39
157.2	156.3	19	167	145	6.263	1.437	-0.87	6.72	6.95
243.3	242.7	81	256	229	5.138	0.571	-0.66	6.32	6.46
247.4	245.6	94	262	236	5.751	0.593	-1.79	6.32	7.27
252.3	252.5	72	276	236	7.568	0.892	0.22	6.45	6.46
257.4	259.3	42	270	246	5.194	0.801	1.86	6.39	7.39
262.6	264.1	21	274	250	5.656	1.234	1.50	6.61	7.26
267.8	270.6	37	282	261	4.474	0.736	2.81	6.37	8.50
272.3	274.1	33	282	266	3.863	0.672	1.82	6.34	7.31
277.4	279.4	38	288	275	3.081	0.500	2.01	6.30	7.47
282.7	284.6	52	293	274	4.011	0.556	1.87	6.30	7.33
287.4	290.1	43	300	279	4.523	0.690	2.77	6.34	8.42
292.3	293.6	35	305	283	4.779	0.808	1.30	6.39	6.89
297.7	299.6	38	307	292	3.909	0.634	1.90	6.32	7.37
302.1	302.5	38	314	288	4.958	0.804	0.36	6.39	6.43
307.3	307.6	25	322	301	4.628	0.926	0.29	6.44	6.46
312.7	311.9	39	328	301	4.436	0.710	-0.79	6.38	6.57
317.5	316.2	31	332	306	5.789	1.040	-1.26	6.54	7.00
322.3	319.7	13	329	309	5.765	1.599	-2.59	7.26	8.92
327.9	324.9	12	336	319	5.869	1.694	-3.00	7.09	9.29
333.3	334.0	24	344	322	6.072	1.239	0.72	6.66	6.81
337.1	336.8	13	346	324	7.369	2.044	-0.26	7.31	7.33
342.4	347.5	15	353	333	5.854	1.511	5.07	6.72	12.16
346.6	352.3	8	359	348	3.615	1.278	5.64	6.78	13.17

Table 4.19 Bin analysis of wind direction as measured by RSD at 40 m height above ground against vane readings at 38.2 m measurement height. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test.

4.5 Correction of Horizontal Wind Speed

The evaluation of the tested RSD showed slightly overestimation in the average of the horizontal wind speed at low measurement heights and underestimation at larger measurement heights. Therefore individual correction functions were calculated for each measurement height and applied to the measured data. The correction functions were applied to the 10-min average values of horizontal wind speed component in every height level of RSD between 60 m and 140 m.

The correction function was calculated by creating a linear regression of horizontal wind speed component measured by the reference anemometer as function of measurand by the RSD of each height.

Measurement Height [m]	Correction function
135	y=0.9419x + 0.5373
130	y=0.9502x + 0.4123
120	y=0.9634x + 0.2773
100	y=0.9780x + 0.1681
80	y=1.0016x - 0.0168
60	y=1.0161x - 0.1941

Table 4.20 Individual correction functions for each height applied to RSD.

The calibration procedure as in chapter 4.2 is applied to the corrected data. The results are shown in the following figures and tables. The correction has the following effects on the results:

- The mean deviation is reduced to the zero.
- The RSD shows a not linear property of the deviation of the horizontal wind speed (see Figure 4.2) which makes it difficult to apply a linear correction function. As a result the correction function does not improve reduce the deviation for all wind speeds.
- Uncertainties (k=2) where reduced by up to 6.2%, but on the other side increased by 11.6% in single wind speed bins (see Table 4.21). On measurement height if 80 m and 60 m the correction shows hardly improvement.
- Correlation and scatter are not influenced by the correction.

	Difference of total uncertainites (*k* =2)					
Wind Speed [m/s]	135 m [%]	130 m [%]	120 m [%]	100 m [%]	80 m [%]	60 m [%]
4.1	-6.7	-0.2	-4.6	-11.6	0.3	4.4
4.5	-6.9	-5.5	-3.1	0.1	0.3	2.8
5.0	4.1	0.3	-2.5	-2.5	0.1	0.2
5.5	-0.1	0.8	0.7	0.7	0.0	1.3
6.0	4.5	3.3	1.1	1.8	-0.1	0.9
6.5	4.2	2.3	1.1	-0.7	-0.1	0.4
7.0	2.7	1.2	0.3	1.7	0.0	-0.2
7.5	2.6	0.8	0.1	0.6	-0.1	0.1
8.0	1.2	0.2	-0.1	0.0	0.0	-0.2
8.5	-0.2	0.1	0.5	0.4	0.0	-0.3
9.0	-0.1	0.7	0.7	1.4	0.0	-0.4
9.5	0.3	1.1	1.0	1.7	0.0	-0.1
10.0	0.5	0.9	1.1	0.3	0.0	-0.5
10.5	0.4	0.5	0.4	1.8	0.0	-0.5
11.0	-0.5	-0.3	-1.1	0.3	0.0	-0.4
11.5	-1.5	-2.0	-1.9	6.2	0.0	
12.0	-1.8	-2.2	-2.1	-4.8		
12.5	-2.2	-2.6	-2.1			
12.9	-2.4	-2.0	0.3			
		-1.3				
13.9	-2.7					

Table 4.21: Differences between the total measurement uncertainties (*k*=2) between uncorrected and corrected data of RSD. Negative values show a deterioration of the corrected data, positive values show an improvement when correction is applied.

It is noted that the uncertainty of the RSD as resulting from this comparison does not reflect all uncertainties of the system during an application at another site. The following additional uncertainties should be considered for an application of the system:

- The RSD measurements are influenced by environmental conditions, like e.g. wind shear. Thus, there is an additional uncertainty due to different environmental conditions during the calibration and during the application of the RSD.
- Mounting errors of the RSD during an application (vertical alignment)

Detailed ambient conditions dependent on wind speed and wind direction which were present during the test can be seen in Appendix A. These are the same as for the uncorrected data presented in chapter 4.2.

4.5.1 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 135 m Measurement Height (correction applied)

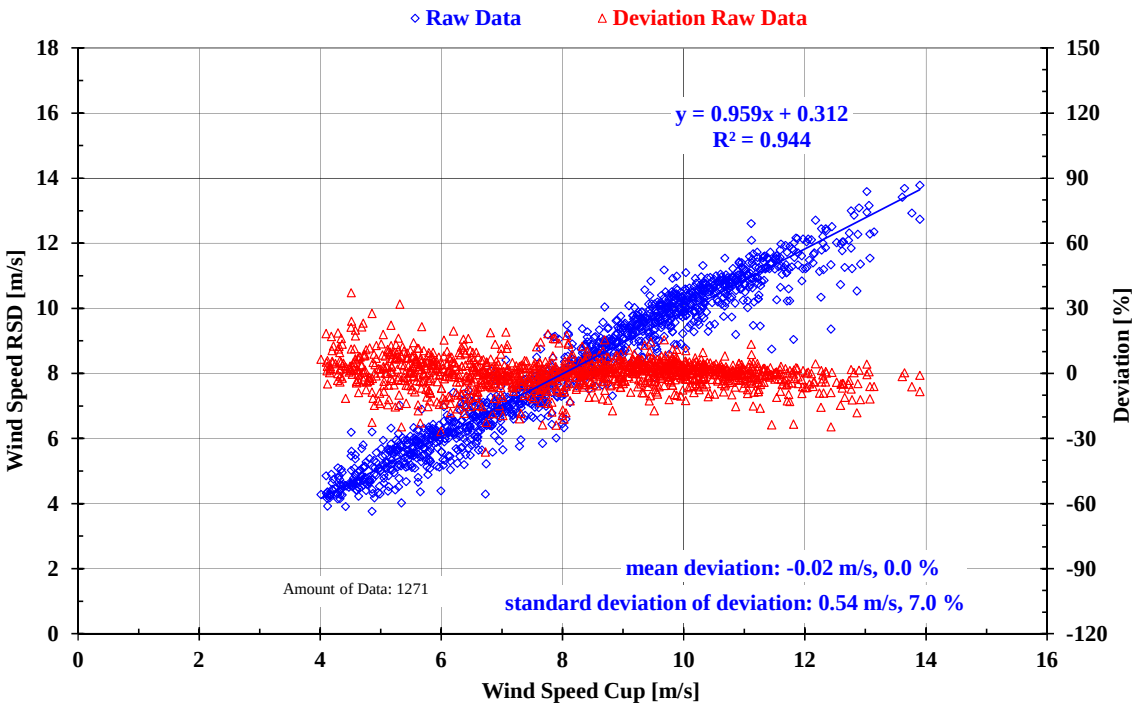

Figure 4.41 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 135 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=0.9419x + 0.5373 was applied to horizontal wind speed component of RSD.

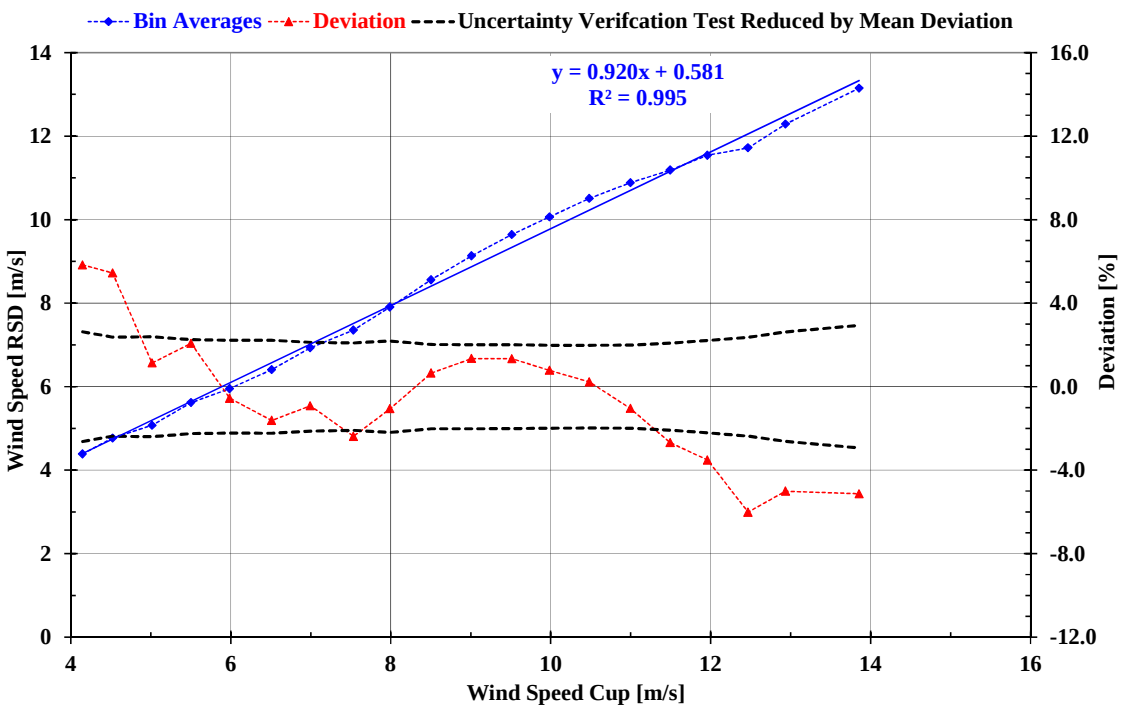

Figure 4.42: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 135 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=0.9419x + 0.5373 was applied to horizontal wind speed component of RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.147	4.388	16	4.898	3.919	0.267	0.067	0.242	5.26	0.218	12.80	0.531
4.522	4.768	63	6.189	3.909	0.420	0.053	0.246	4.74	0.214	11.88	0.537
5.016	5.073	62	6.321	3.759	0.517	0.066	0.057	4.79	0.240	5.30	0.266
5.503	5.617	84	7.018	4.022	0.486	0.053	0.114	4.50	0.248	6.12	0.337
5.987	5.953	77	7.413	4.390	0.519	0.059	-0.033	4.45	0.266	4.58	0.274
6.511	6.406	84	7.479	4.286	0.585	0.064	-0.105	4.45	0.290	5.50	0.358
6.996	6.931	78	8.412	5.576	0.486	0.055	-0.064	4.25	0.297	4.63	0.324
7.534	7.355	79	8.741	5.755	0.493	0.056	-0.179	4.18	0.315	6.34	0.477
7.989	7.905	77	9.485	6.010	0.701	0.080	-0.085	4.38	0.350	4.86	0.389
8.504	8.560	92	10.041	7.507	0.445	0.046	0.056	4.04	0.344	4.25	0.361
9.011	9.132	79	10.079	7.310	0.461	0.052	0.121	4.03	0.363	4.84	0.436
9.514	9.641	104	11.181	7.884	0.533	0.052	0.128	4.01	0.382	4.83	0.460
9.985	10.063	107	11.096	8.581	0.472	0.046	0.078	3.97	0.397	4.27	0.426
10.483	10.507	78	11.539	9.288	0.428	0.048	0.024	3.96	0.415	3.99	0.418
10.996	10.882	80	12.603	9.193	0.517	0.058	-0.114	3.99	0.438	4.50	0.494
11.494	11.185	44	11.972	8.741	0.605	0.091	-0.308	4.16	0.478	6.79	0.781
11.960	11.540	27	12.707	9.043	0.706	0.136	-0.420	4.43	0.529	8.30	0.992
12.468	11.718	21	12.509	9.363	0.786	0.172	-0.750	4.73	0.590	12.92	1.611
12.936	12.288	14	13.583	10.531	0.885	0.237	-0.647	5.23	0.677	11.30	1.461
13.857	13.146	3	13.780	12.735	0.557	0.322	-0.711	5.88	0.814	11.82	1.639

Table 4.22 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 135 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=0.9419x + 0.5373 was applied to horizontal wind speed component of RSD.

4.5.2 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 130 m Measurement Height (correction applied)

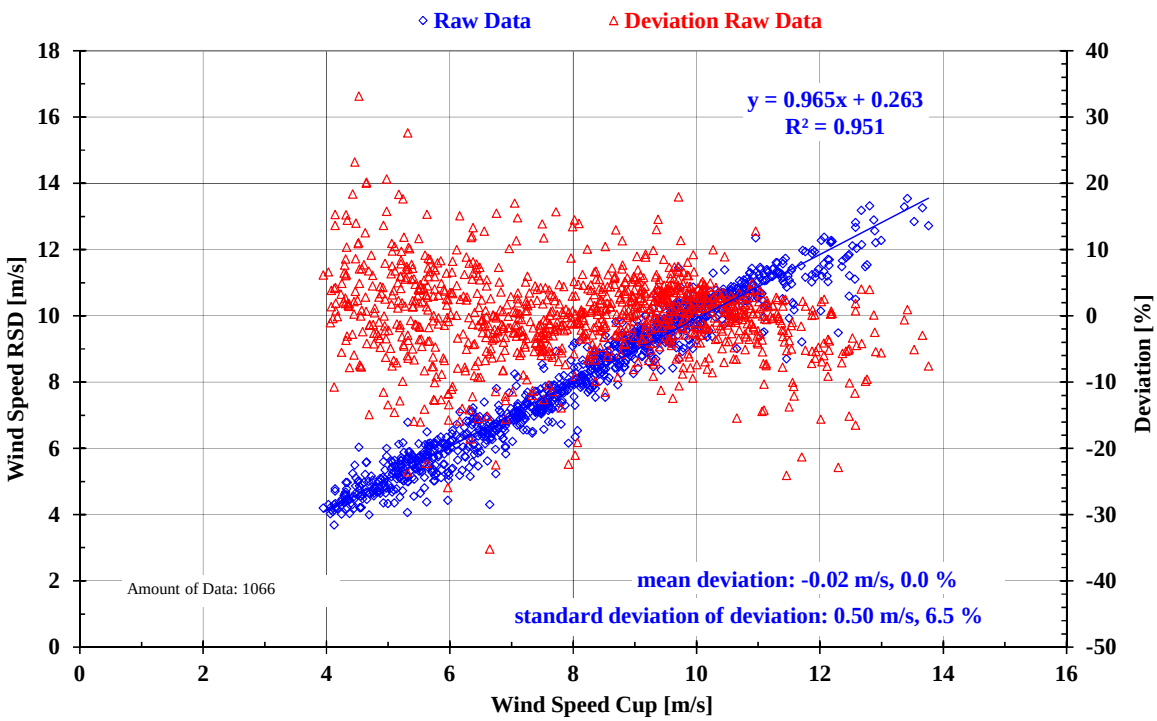

Figure 4.43 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 130 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=0.9502x + 0.4123 was applied to horizontal wind speed component of RSD.

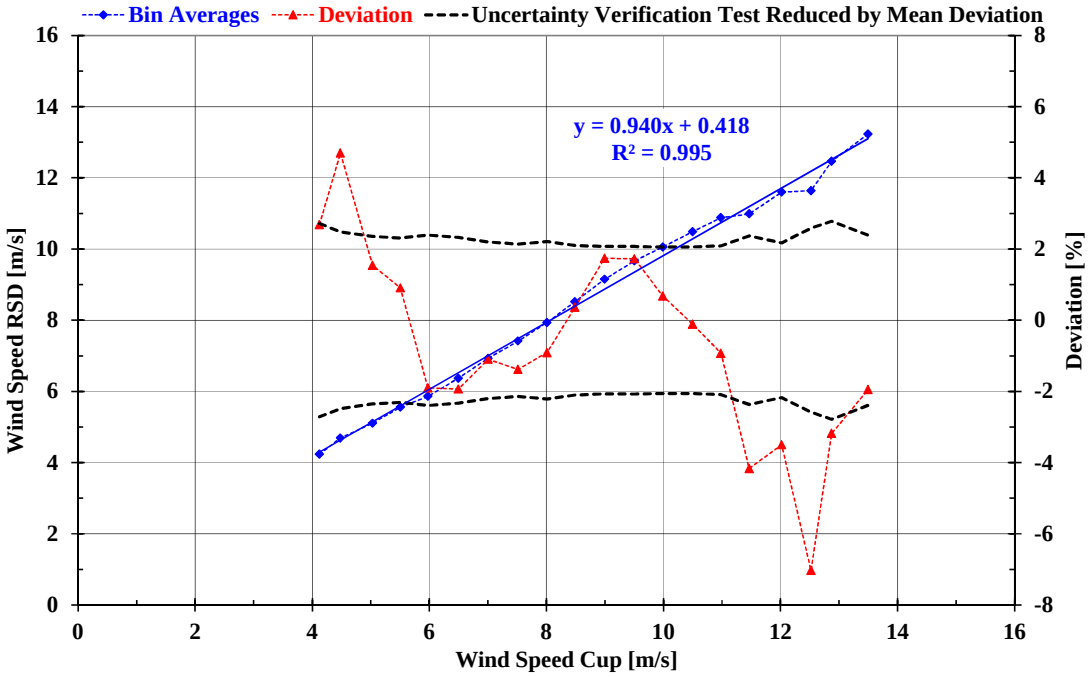

Figure 4.44: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=0.9502x + 0.4123 was applied to horizontal wind speed component of RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.123	4.234	16	4.774	3.681	0.257	0.064	0.111	5.4	0.224	7.6	0.315
4.482	4.692	54	6.028	3.995	0.415	0.056	0.211	5.0	0.222	10.6	0.476
5.029	5.107	61	6.171	4.327	0.434	0.056	0.078	4.7	0.237	5.6	0.283
5.506	5.556	75	6.788	4.061	0.451	0.052	0.050	4.6	0.254	5.0	0.273
5.975	5.862	52	7.092	4.422	0.526	0.073	-0.114	4.8	0.286	6.1	0.365
6.496	6.371	66	7.396	4.308	0.540	0.067	-0.126	4.7	0.302	6.1	0.393
7.007	6.931	63	8.251	5.828	0.455	0.057	-0.077	4.4	0.308	4.9	0.344
7.517	7.413	69	8.936	6.456	0.415	0.050	-0.104	4.3	0.322	5.1	0.383
8.011	7.938	62	9.221	6.152	0.586	0.074	-0.073	4.4	0.354	4.8	0.383
8.487	8.518	73	9.819	7.539	0.439	0.051	0.031	4.2	0.356	4.3	0.362
8.994	9.150	78	10.028	8.251	0.375	0.042	0.157	4.1	0.372	5.4	0.487
9.505	9.669	105	11.454	8.365	0.508	0.050	0.164	4.1	0.394	5.4	0.513
9.988	10.057	89	10.865	8.917	0.428	0.045	0.068	4.1	0.411	4.3	0.433
10.499	10.487	65	11.387	9.012	0.397	0.049	-0.012	4.1	0.433	4.1	0.433
10.981	10.880	56	12.356	9.468	0.488	0.065	-0.102	4.2	0.459	4.6	0.502
11.464	10.987	29	11.976	8.698	0.743	0.138	-0.477	4.7	0.543	9.6	1.099
12.020	11.600	25	12.375	10.142	0.540	0.108	-0.421	4.3	0.523	8.2	0.991
12.522	11.641	17	13.183	9.487	0.905	0.219	-0.881	5.2	0.647	15.0	1.877
12.873	12.464	6	13.316	11.539	0.613	0.250	-0.409	5.6	0.716	8.4	1.087
13.496	13.233	4	13.544	12.841	0.291	0.146	-0.263	4.8	0.645	6.2	0.832

Table 4.23 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=0.9502x + 0.4123 was applied to horizontal wind speed component of RSD.

4.5.3 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 120 m Measurement Height (correction applied)

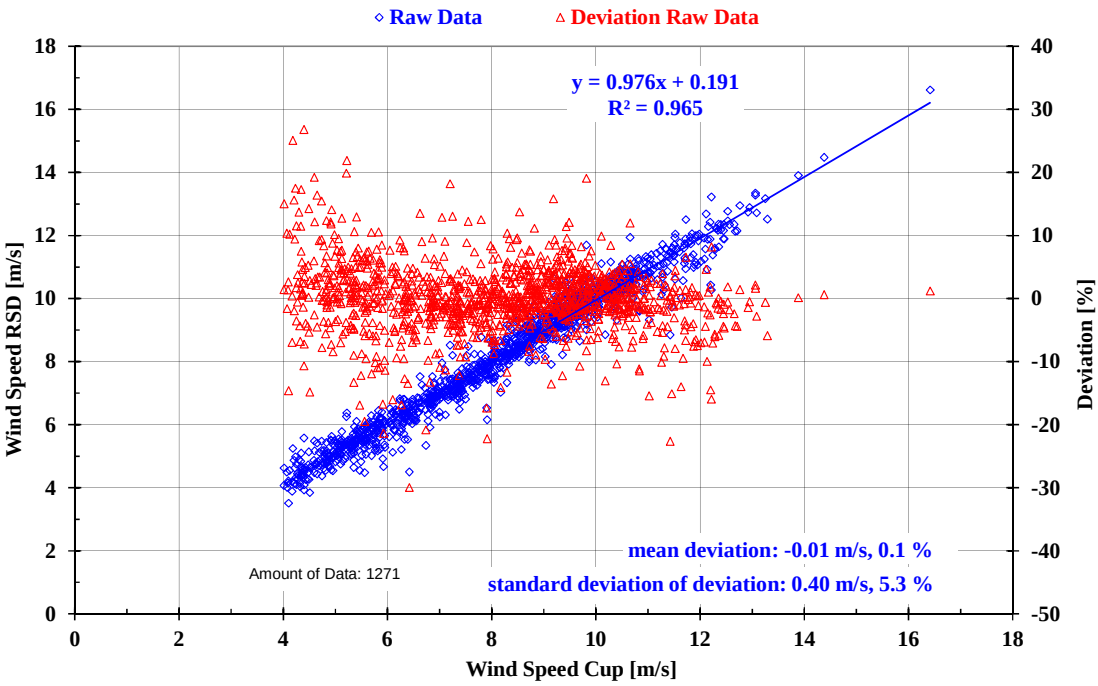

Figure 4.45 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 120 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=0.9634x + 0.2773 was applied to horizontal wind speed component of RSD.

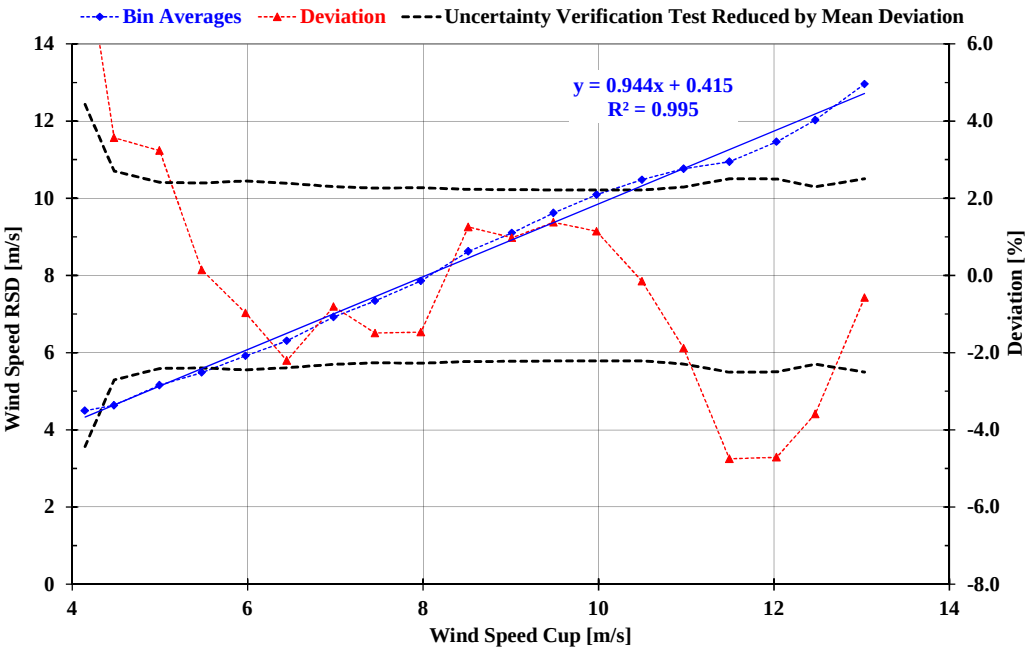

Figure 4.46: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=0.9634x + 0.2773 was applied to horizontal wind speed component of RSD.

v (Refer-ence)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Refer-ence)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.145	4.495	10	5.239	3.505	0.516	0.163	0.351	8.87	0.367	19.10	0.792
4.477	4.637	41	5.576	3.842	0.439	0.068	0.160	5.41	0.242	8.96	0.401
4.996	5.158	64	6.366	4.536	0.364	0.045	0.162	4.82	0.241	8.07	0.403
5.477	5.485	67	6.289	4.478	0.384	0.047	0.008	4.79	0.262	4.80	0.263
5.978	5.919	53	6.819	4.661	0.476	0.065	-0.058	4.90	0.293	5.27	0.315
6.448	6.305	61	7.522	4.497	0.476	0.061	-0.142	4.78	0.308	6.50	0.419
6.981	6.924	65	8.514	5.913	0.413	0.051	-0.056	4.60	0.321	4.88	0.340
7.453	7.342	69	8.476	6.482	0.372	0.045	-0.111	4.53	0.337	5.42	0.404
7.976	7.858	74	8.774	6.154	0.435	0.051	-0.117	4.55	0.363	5.41	0.432
8.515	8.622	86	9.709	7.329	0.406	0.044	0.107	4.46	0.380	5.12	0.436
9.015	9.103	90	10.643	7.907	0.439	0.046	0.088	4.45	0.401	4.86	0.438
9.488	9.619	93	10.634	8.216	0.430	0.045	0.131	4.43	0.420	5.22	0.495
9.979	10.093	78	11.694	8.852	0.432	0.049	0.114	4.43	0.442	4.99	0.497
10.497	10.481	64	11.934	9.324	0.427	0.053	-0.016	4.42	0.464	4.43	0.466
10.971	10.764	32	11.385	9.324	0.504	0.089	-0.206	4.59	0.503	5.93	0.651
11.493	10.947	25	12.040	8.842	0.758	0.152	-0.546	5.01	0.576	10.74	1.235
12.031	11.464	20	13.216	10.268	0.685	0.153	-0.567	5.00	0.602	10.67	1.283
12.473	12.026	10	12.763	11.539	0.392	0.124	-0.447	4.59	0.573	8.52	1.062
13.034	12.959	3	13.274	12.715	0.286	0.165	-0.075	5.01	0.653	5.14	0.670

Table 4.24 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=0.9634x + 0.2773 was applied to horizontal wind speed component of RSD.

4.5.4 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 100 m Measurement Height (correction applied)

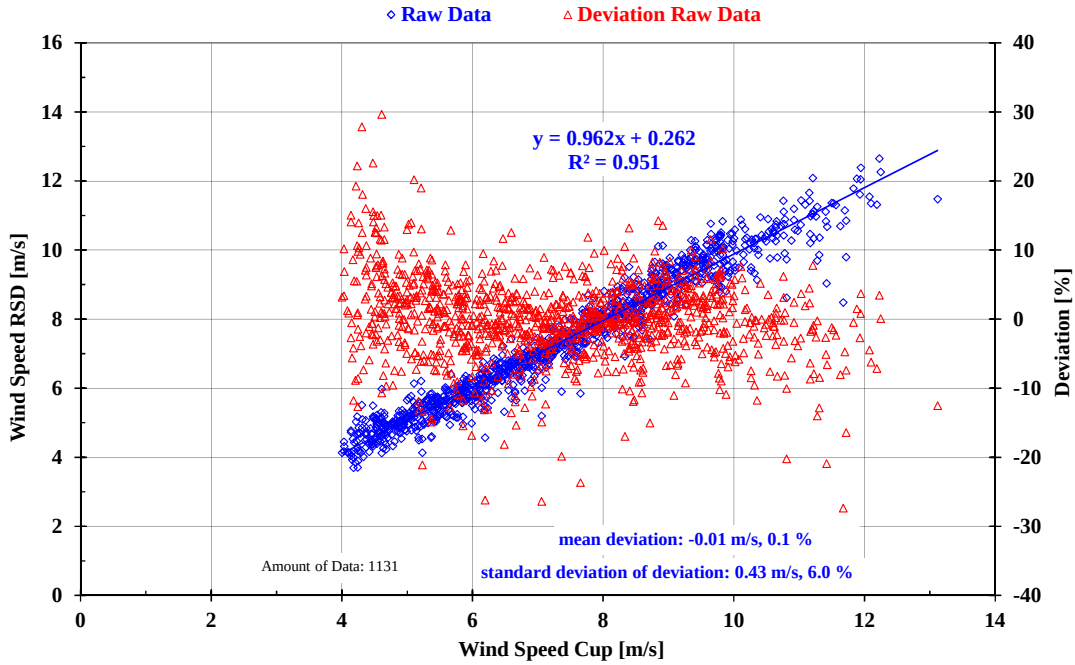

Figure 4.47 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 100 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=0.9780x + 0.1681 was applied to horizontal wind speed component of RSD.

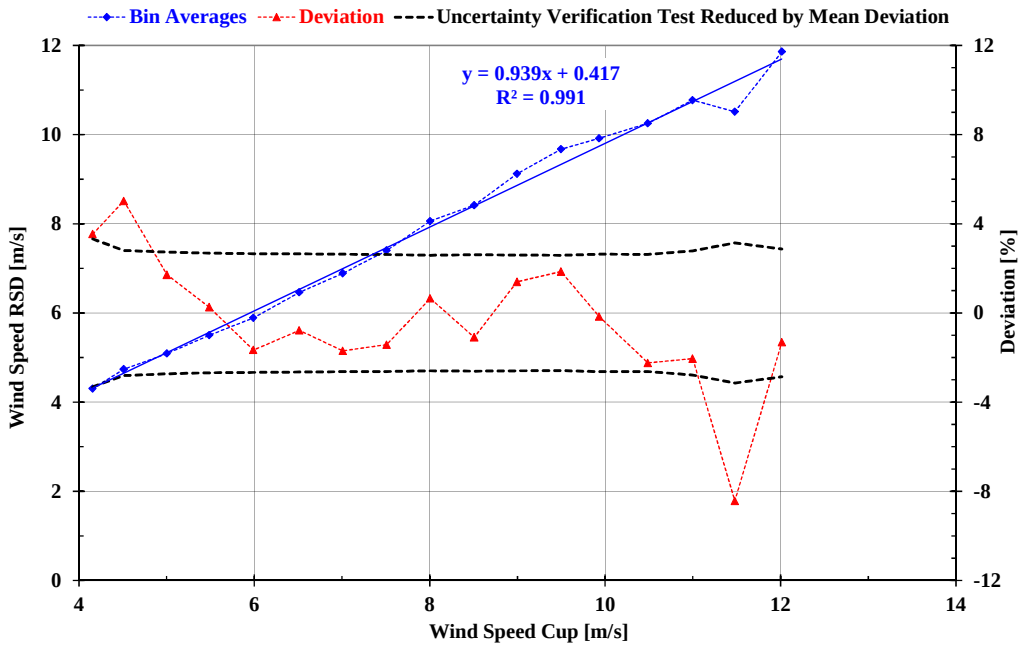

Figure 4.48: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=0.9780x + 0.1681 was applied to horizontal wind speed component of RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.157	4.304	23	5.175	3.689	0.389	0.081	0.147	6.63	0.276	9.69	0.403
4.512	4.738	84	5.977	3.885	0.369	0.040	0.226	5.61	0.253	11.50	0.519
5.003	5.089	90	6.202	4.129	0.359	0.038	0.086	5.46	0.273	6.45	0.323
5.487	5.501	88	6.398	4.569	0.304	0.032	0.014	5.36	0.294	5.38	0.295
5.989	5.889	104	6.750	4.569	0.360	0.035	-0.100	5.32	0.319	6.28	0.376
6.513	6.462	88	7.425	5.312	0.352	0.037	-0.051	5.30	0.345	5.52	0.360
7.008	6.889	86	7.748	5.195	0.394	0.042	-0.119	5.27	0.369	6.27	0.440
7.509	7.402	86	8.276	5.841	0.398	0.043	-0.107	5.24	0.394	5.96	0.448
8.006	8.059	86	8.941	7.308	0.338	0.036	0.052	5.18	0.415	5.34	0.428
8.508	8.415	96	9.508	6.916	0.478	0.049	-0.093	5.22	0.444	5.66	0.482
8.995	9.121	87	10.124	8.080	0.407	0.044	0.125	5.19	0.466	5.89	0.530
9.496	9.672	74	10.760	8.403	0.410	0.048	0.176	5.17	0.491	6.36	0.604
9.931	9.916	54	10.877	8.784	0.538	0.073	-0.016	5.27	0.523	5.28	0.524
10.487	10.252	31	10.946	9.136	0.465	0.084	-0.235	5.25	0.551	6.90	0.724
10.999	10.773	26	12.080	8.618	0.700	0.137	-0.226	5.57	0.612	6.91	0.760
11.479	10.512	17	11.356	8.481	0.857	0.208	-0.968	6.28	0.721	17.99	2.065
12.016	11.858	9	12.647	11.317	0.460	0.153	-0.157	5.73	0.689	6.30	0.757

Table 4.25 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=0.9780x + 0.1681 was applied to horizontal wind speed component of RSD.

4.5.5 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 80 m Measurement Height (correction applied)

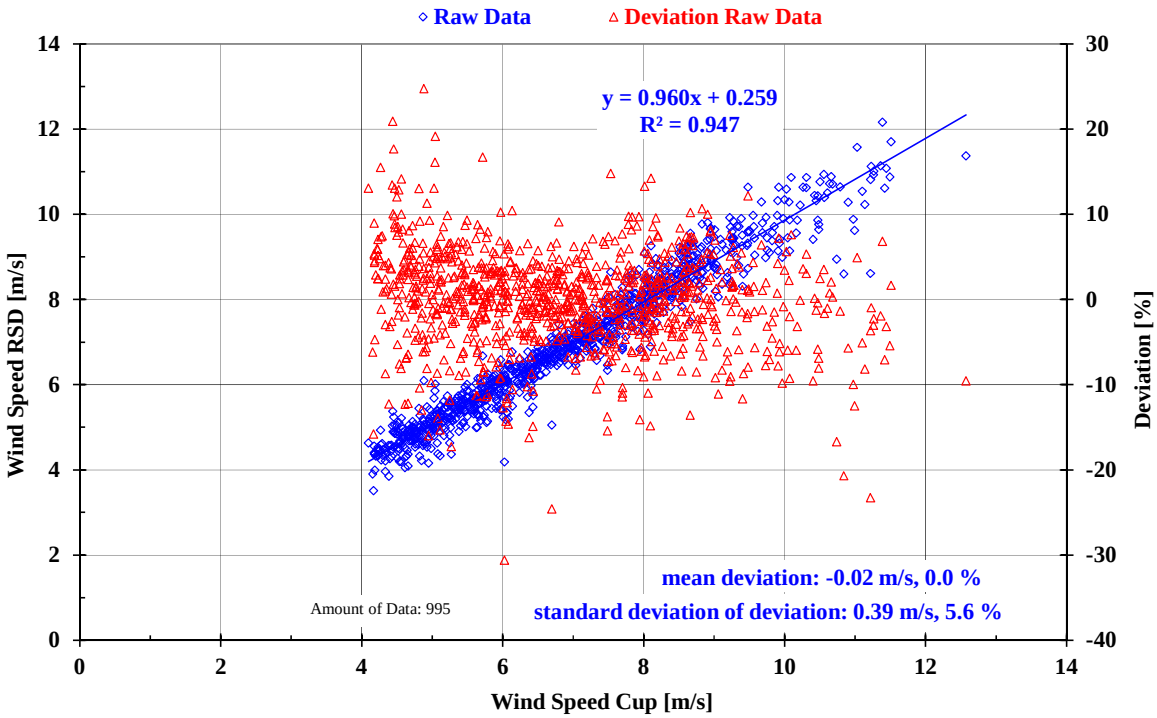

Figure 4.49 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 80 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=1.0016x - 0.0168 was applied to horizontal wind speed component of RSD.

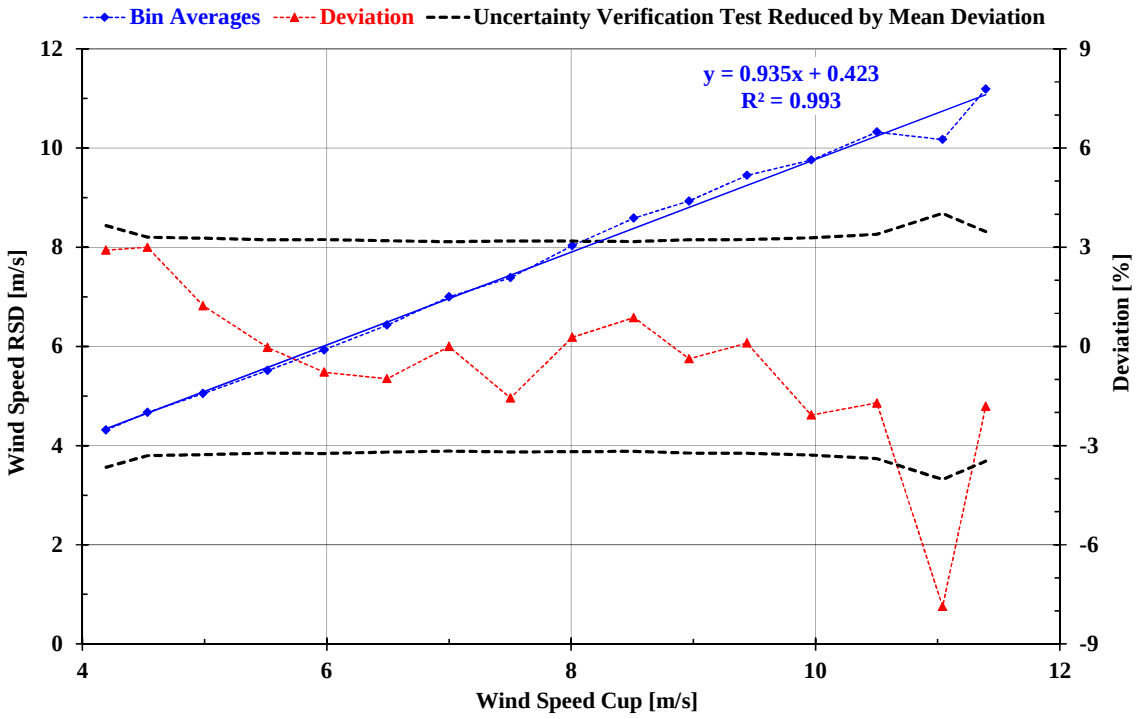

Figure 4.50: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 80 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=1.0016x - 0.0168 was applied to horizontal wind speed component of RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.193	4.315	16	4.631	3.509	0.285	0.071	0.122	7.31	0.306	9.34	0.392
4.532	4.668	81	5.372	3.849	0.311	0.035	0.136	6.61	0.300	8.92	0.404
4.987	5.049	99	6.093	4.160	0.366	0.037	0.061	6.54	0.326	6.99	0.349
5.516	5.514	106	6.674	4.360	0.328	0.032	-0.002	6.45	0.356	6.45	0.356
5.978	5.932	96	6.774	4.180	0.392	0.040	-0.046	6.47	0.387	6.65	0.398
6.493	6.430	96	7.105	5.051	0.340	0.035	-0.063	6.39	0.415	6.68	0.434
7.000	7.000	95	7.615	6.444	0.259	0.027	0.000	6.34	0.444	6.34	0.444
7.503	7.387	85	8.647	6.333	0.410	0.044	-0.117	6.38	0.479	7.10	0.533
8.010	8.033	97	9.258	6.824	0.448	0.045	0.022	6.37	0.510	6.39	0.512
8.514	8.588	79	9.548	7.485	0.424	0.048	0.074	6.34	0.540	6.58	0.560
8.966	8.932	49	9.919	8.006	0.487	0.070	-0.034	6.45	0.578	6.49	0.582
9.440	9.449	34	10.630	8.306	0.465	0.080	0.010	6.46	0.610	6.47	0.611
9.965	9.758	24	10.861	8.988	0.543	0.111	-0.207	6.57	0.655	7.77	0.775
10.502	10.322	18	10.931	8.948	0.566	0.133	-0.179	6.79	0.713	7.60	0.798
11.040	10.172	11	11.572	8.597	0.947	0.285	-0.868	8.04	0.888	17.67	1.950
11.394	11.187	8	12.163	10.610	0.502	0.178	-0.206	6.94	0.790	7.82	0.892

Table 4.26 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 80 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=1.0016x - 0.0168 was applied to horizontal wind speed component of RSD.

4.5.6 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 60 m Measurement Height (correction applied)

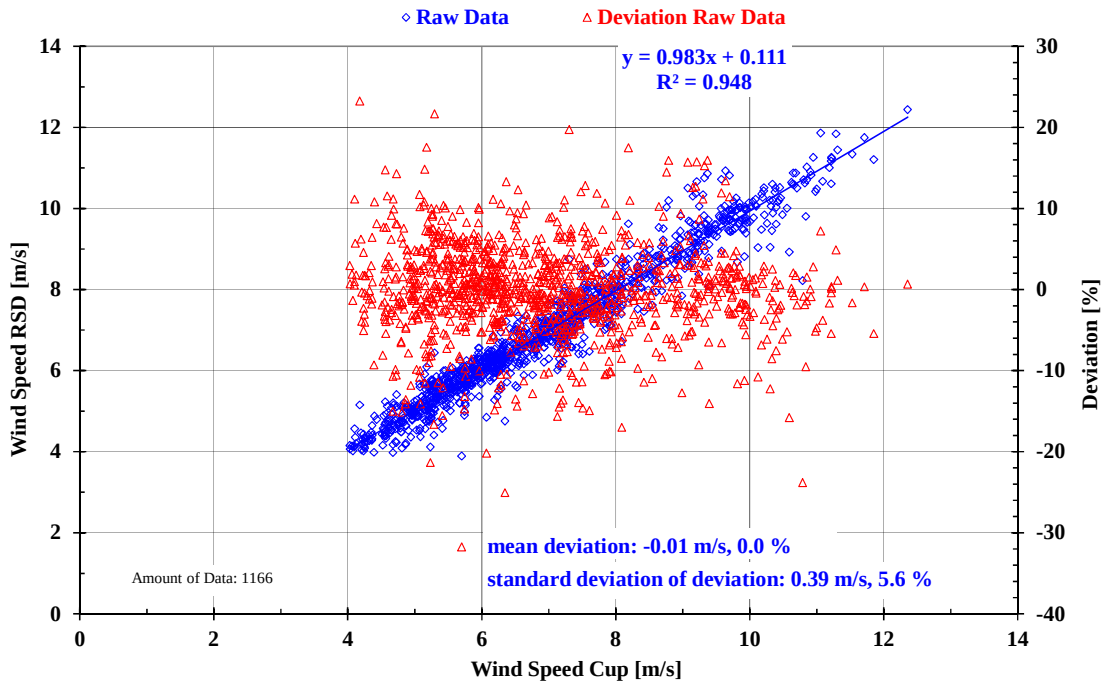

Figure 4.51 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 60 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average. A correction offset of y=1.0161x - 0.1941 was applied to horizontal wind speed component of RSD.

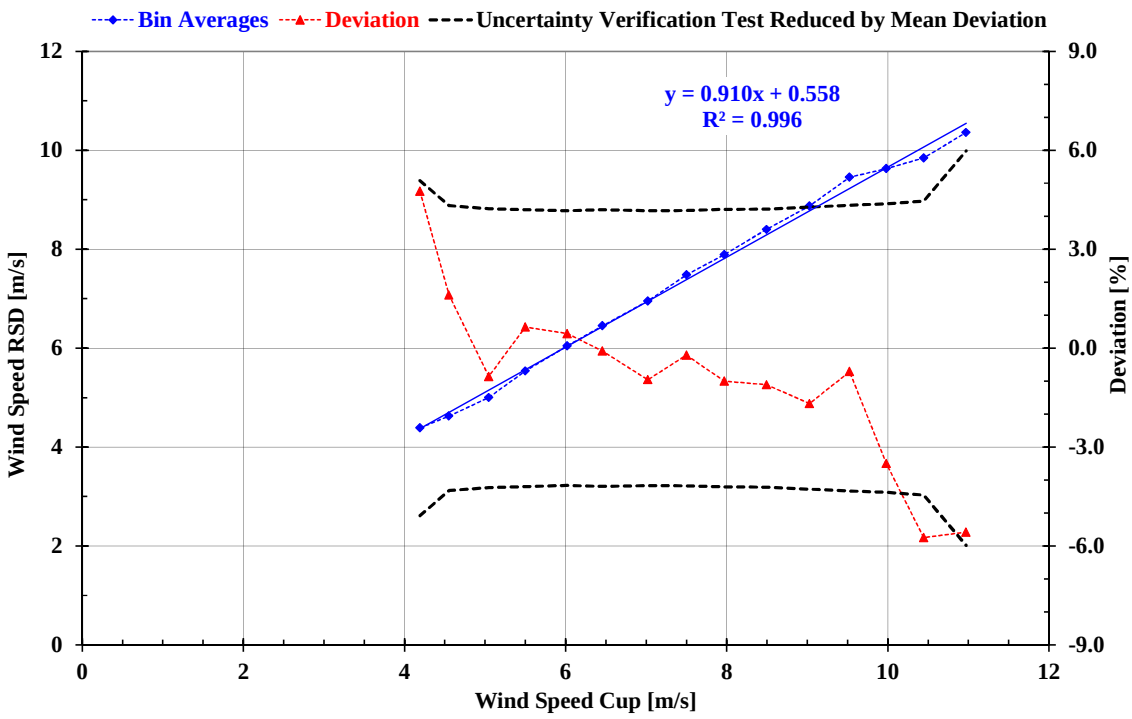

Figure 4.52: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. A correction offset of y=1.0161x - 0.1941 was applied to horizontal wind speed component of RSD.

v (Reference)	v (RSD)	number of data sets	v (RSD) max	v (RSD) min	v (RSD) std	v (RSD) std/sqrt(n)	v (RSD) - v (Reference)	uncertainty (*k* =2) (calibration)		uncertainty (*k* =2) v (RSD)	
[m/s]	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[%]	[m/s]	[%]	[m/s]
4.190	4.390	9	5.151	4.023	0.339	0.113	0.199	10.162	0.426	13.918	0.583
4.552	4.626	44	5.405	3.972	0.362	0.055	0.073	8.639	0.393	9.220	0.420
5.045	5.002	93	6.085	4.084	0.390	0.040	-0.043	8.457	0.427	8.629	0.435
5.501	5.536	119	6.441	3.891	0.373	0.034	0.035	8.398	0.462	8.495	0.467
6.020	6.047	121	6.858	4.846	0.306	0.028	0.027	8.330	0.501	8.377	0.504
6.457	6.452	85	7.356	4.754	0.454	0.049	-0.006	8.391	0.542	8.393	0.542
7.019	6.952	97	8.036	5.892	0.434	0.044	-0.067	8.338	0.585	8.554	0.600
7.499	7.483	85	8.748	6.411	0.489	0.053	-0.016	8.349	0.626	8.359	0.627
7.969	7.889	56	9.621	6.715	0.554	0.074	-0.080	8.417	0.671	8.651	0.689
8.492	8.398	32	9.530	7.457	0.503	0.089	-0.094	8.433	0.716	8.721	0.741
9.026	8.875	26	10.363	7.843	0.604	0.118	-0.152	8.551	0.772	9.189	0.829
9.524	9.456	15	10.058	8.077	0.563	0.145	-0.068	8.665	0.825	8.781	0.836
9.980	9.631	13	10.434	8.676	0.558	0.155	-0.349	8.750	0.873	11.205	1.118
10.445	9.845	10	10.597	8.920	0.588	0.186	-0.600	8.913	0.931	14.542	1.519
10.972	10.360	6	11.857	8.219	1.265	0.516	-0.612	11.963	1.313	16.358	1.795

Table 4.27 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD. The right column shows the total expanded uncertainty (k=2) of the RSD as derived from the test. A correction offset of y=1.0161x - 0.1941 was applied to horizontal wind speed component of RSD.

4.6 Accuracy of the RSD in Terms of Sigma w

The standard deviation of the vertical wind speed component *sigma w* as measured by the RSD and by the ultra-sonic anemometers is compared for measurement heights of 130 m and 120 m in the following sub chapter. The following conclusions can be drawn:

- The RSD shows similar results for both evaluated measurement heights of 130 m and 100 m. With increasing the vertical standard deviation of the reference the overestimation of the standard uncertainty reduces.
- The squared correlation is between about 0.47 for measurement height of 130 m and 0.61 for measurement height of 100 m.

4.6.1 Accuracy of RSD in Terms of 10-Minute Averages of sigma w at 130 m Measurement Height

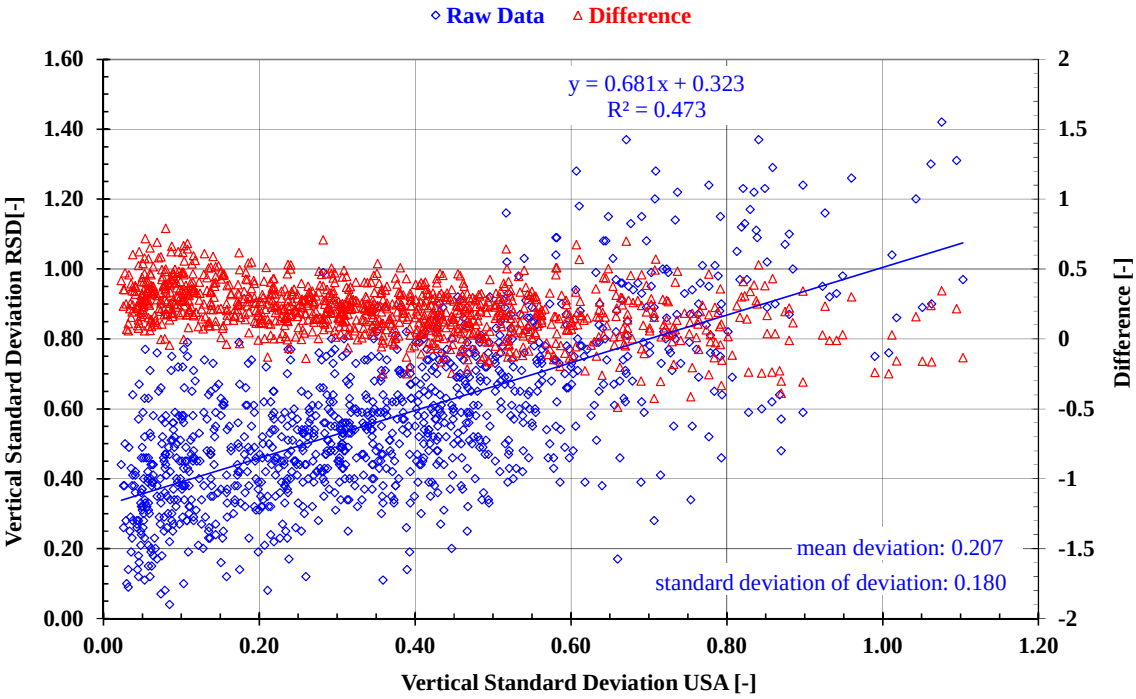

Figure 4.53 Scatter plot of standard deviation of vertical wind speed component (sigma w) as measured by RSD at 140 m against ultra-sonic anemometer readings at 130 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

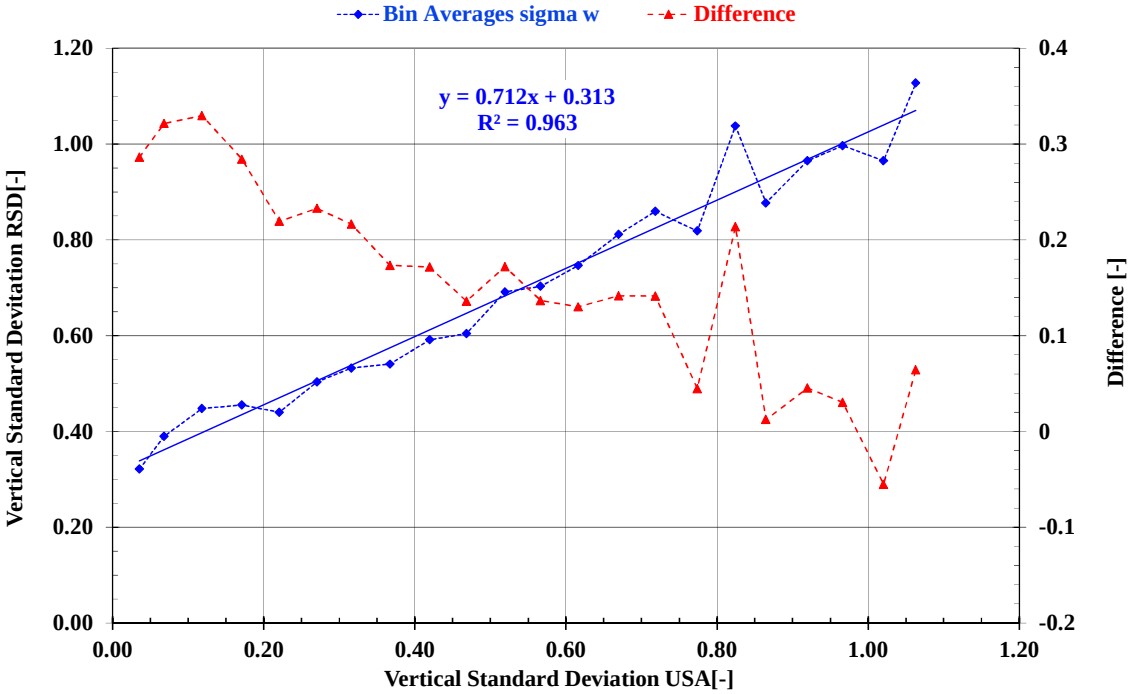

Figure 4.54: Bin analysis of 10-minute averages of standard deviation of vertical wind speed component (sigma w) measured by RSD in 140 m against ultra-sonic measurement at 130 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

4.6.2 Accuracy of RSD in Terms of 10-Minute Averages of sigma w at 100 m Measurement Height

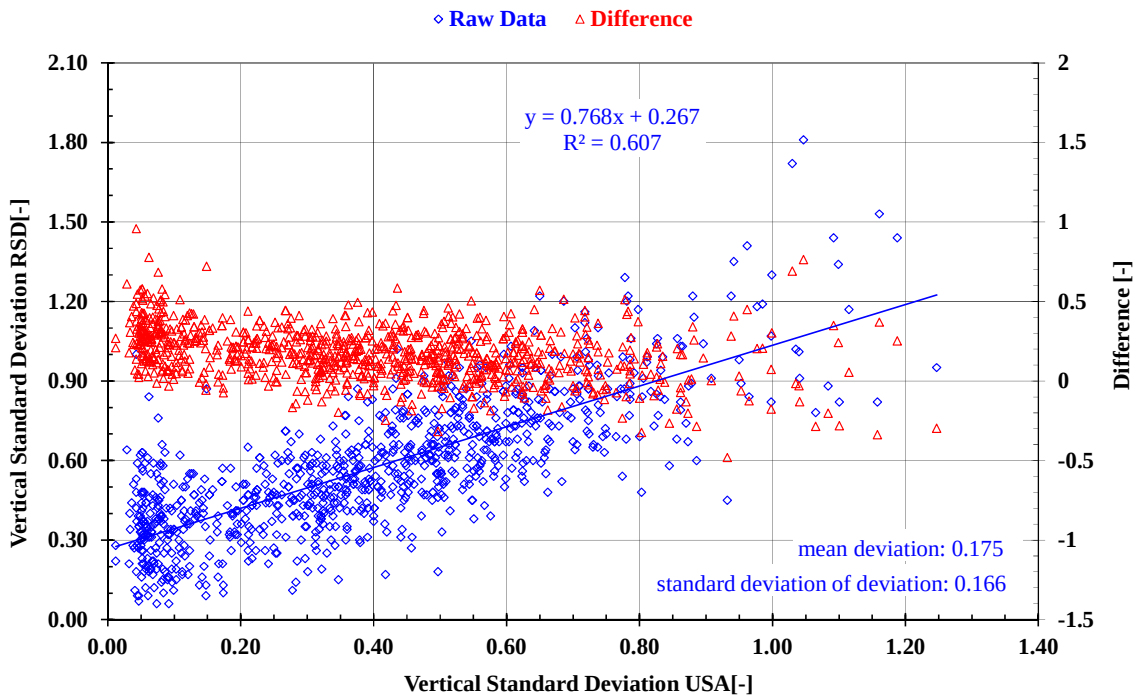

Figure 4.55 Scatter plot of standard deviation of vertical wind speed component (sigma w) as measured by RSD at 100 m against ultra-sonic anemometer readings at 100 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

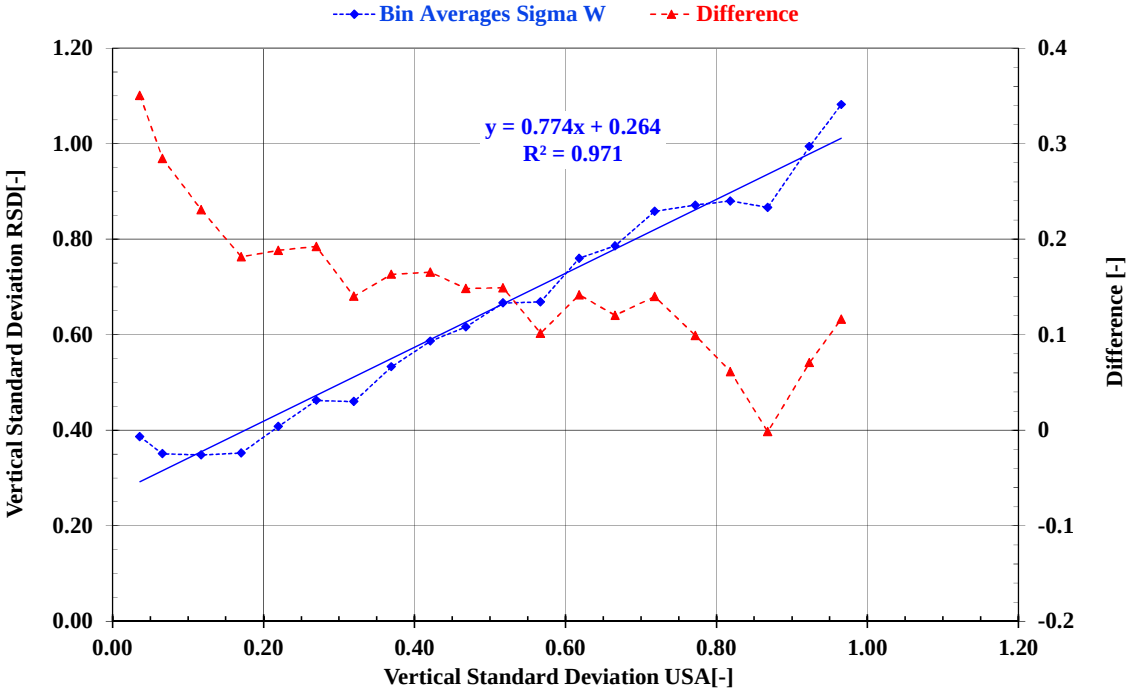

Figure 4.56: Bin analysis of 10-minute averages of standard deviation of vertical wind speed component (sigma w) measured by RSD in 100 m against ultra-sonic measurement at 100 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

5 Conclusions

The accuracy of the sodar of type PA-XS, serial number 597, has been tested against cup anemometers mounted between 40 m and 135 m measurement height on a 135 m high met tower in flat terrain. The met mast is equipped with cup anemometers of high accuracy class and vanes at height levels of about 135 m, 131 m, 120 m, 100 m, 80 m 60 m and 40 m. All anemometers have been calibrated according to MEASNET by Deutsche WindGuard Wind Tunnel Services GmbH. The respective wind tunnel of Deutsche WindGuard is applied by the German Authority for the standardisation of units, Physikalisch-Technische Bundesanstalt (PTB), as German reference for the definition of the unit m/s in airflow measurements. A more accurate reference for cup anemometers is not available. The anemometers on the mast are mounted according to IEC 61400-12-1 [2]. Mast influences at the lower measurement heights like blockage and flow acceleration effects have been corrected empirically. Wind directions with the sensors of the mast or with the RSD in wakes of the mast or of neighbouring wind turbines have been excluded from the test.

The data evaluation covers a calibration, which describes the accuracy of the tested sodar unit under the conditions during the test.

The main results of the calibration are:

- Depending on measurement height, the database consists of 892 to 1271 10-minute datasets (1080 are required). Only wind speed bins up to 14 m/s are completed (up to 16 m/s is required). Therefore, the database available for the verification test at hand does not fulfil the completeness criteria of the draft IEC 61400-12-1, ed. 2. This deviation is not serious as completed test allows a good estimation of the instruments performance.
- The RSD shows a good correlation to cup anemometer measurements in terms of 10-minute averages of the horizontal wind speed component. At heights 140 m to 60 m measurement height the square of correlation coefficient is 0.94 to 0.96. Due to site effects the correlation decreases for lower measurement height (for 40 m to about 0.89). The evaluations of horizontal wind speed where the speed filter (>4m/s) was not applied the correlations showed slightly higher values (of about 0.1) which can be seen in the appendix 8.3.
- The horizontal wind speed component of the RSD shows in average low values between -1.3% to 1% for measurement heights between 135 m to 60 m, which is considered as good.
- With increasing measurement height the averaged wind horizontal wind speed component shows a slightly tendency for underestimation (1% at 60m and -1.3% at 135m).
- The resulting wind speed dependent uncertainties of the measurements of the horizontal wind speed component by the RSD are in the order of about 5-8% (expanded uncertainty k=2) in most wind speed bins for all measurement heights. The variation of the uncertainty reaches from 4% to 23.9% for the different measurement heights and wind speed bins.
- For measurement heights between 135 m and 60 m individual corrections functions were applied to horizontal wind speed component. These improvements were successful to varying degrees.

- The wind direction as measured by the RSD correlates good to the wind direction as measured by vane on the met mast (squared correlation coefficient above 0.99).
- The RSD shows a data availability of about 73 % up to 100 m. Above 100 m the availability decreases to 61 % at 160 m. Especially during too heavy rain and strong wind the instrument discards measurement values.

It is pointed out that all shown uncertainties of the measurement of the RSD represent two standard uncertainties (expanded uncertainty k=2) as it is required according to DWG's accreditation for calibrations of RSD's. In contrast to that, it is common practice to apply only the single standard uncertainty of wind measurements for most applications throughout the wind energy industry as for instance in case of wind resource assessments or wind turbine power curve tests. The expanded uncertainty (k=2) with the confidence of 95% has the twice uncertainty. To get the single uncertainty (k=1) with confidence of 68%, the expanded uncertainty has to be divided by two.

6 Literature

[1] IEC 61400-12-1, Wind turbines, Part 12-1: Power performance measurements of electricity producing wind turbines, 2005
[2] IEC 61400-12-1, ed. 2, Wind turbines, Part 12-1: Power performance measurements of electricity producing wind turbines, second edition, 2017
[3] Thies First Class Advanced, Summary of Cup Anemometer Classification according to IEC 61400-12-1, Deutsche WindGuard Wind Tunnel Services GmbH, 2008-12-22
[4] MEASNET; Cup Anemometer Calibration Procedure, Version 2, October 2009

7 Acknowledgement

Thanks belong to Enercon, especially Mr. Jürgen Stoltenjohannes, to make available the test site and met mast for the measurements.

8 Appendix A, Ambient Conditions at Calibration Test

8.1 Ambient conditions dependent on wind speed

This chapter presents detailed ambient conditions during test dependent on wind speed.

Height 135.0 m	Depen-dency	shear exponent alpha 135m-100m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9	4.15	0.347	0.402	0.113	0.047	171	76	12.4	2.5	-0.8	1.1	1.219	0.010	13.1	15.7	1.022	1.587
10	4.52	0.324	0.330	0.089	0.048	143	80	11.9	4.0	-0.1	1.8	1.219	0.013	13.2	14.8	1.298	1.857
11	5.02	0.238	0.336	0.067	0.044	198	71	12.8	2.8	0.6	2.0	1.216	0.010	10.2	19.7	1.675	1.337
12	5.50	0.320	0.235	0.082	0.059	287	56	11.1	3.2	0.2	1.9	1.221	0.011	18.8	17.2	0.981	1.201
13	5.99	0.375	0.233	0.083	0.049	288	52	10.5	3.1	-0.1	1.8	1.224	0.015	19.0	18.6	0.733	1.066
14	6.51	0.324	0.190	0.079	0.050	298	42	10.2	2.4	0.1	1.8	1.225	0.011	18.6	16.4	0.695	1.104
15	7.00	0.358	0.224	0.084	0.044	280	56	10.6	3.1	-0.4	1.2	1.223	0.016	13.9	12.8	0.881	1.132
16	7.53	0.408	0.166	0.074	0.035	273	47	9.5	2.8	-0.5	1.0	1.226	0.013	11.7	10.0	0.768	1.008
17	7.99	0.397	0.214	0.078	0.044	272	46	9.5	2.7	-0.3	1.2	1.226	0.011	13.4	9.8	0.836	0.968
18	8.50	0.445	0.152	0.075	0.035	270	43	9.9	3.2	-0.2	1.0	1.223	0.014	13.1	6.8	1.048	0.893
19	9.01	0.461	0.169	0.078	0.038	269	49	10.5	3.0	-0.3	0.9	1.221	0.013	12.5	7.1	0.928	0.843
20	9.51	0.431	0.146	0.079	0.034	273	41	10.5	3.2	-0.4	0.8	1.218	0.013	10.9	5.5	0.989	0.811
21	9.98	0.423	0.125	0.076	0.035	264	38	10.1	3.3	-0.2	0.9	1.221	0.015	10.7	6.4	1.169	0.693
22	10.48	0.445	0.103	0.083	0.031	272	35	9.9	2.5	-0.4	0.8	1.223	0.009	9.6	5.4	1.029	0.772
23	11.00	0.410	0.093	0.093	0.038	270	44	10.4	2.6	-0.6	0.6	1.220	0.011	7.1	3.8	1.086	0.928
24	11.49	0.408	0.129	0.095	0.040	275	44	10.7	2.6	-0.6	0.6	1.219	0.013	6.9	3.6	0.934	1.018
25	11.96	0.347	0.130	0.124	0.029	273	32	11.4	2.3	-0.9	0.5	1.212	0.013	4.5	2.4	1.112	0.884
26	12.47	0.414	0.099	0.110	0.025	285	23	9.7	2.7	-0.6	0.4	1.217	0.013	6.8	2.5	0.835	0.643
27	12.94	0.386	0.084	0.106	0.025	278	25	10.6	2.9	-0.6	0.5	1.213	0.013	6.6	2.8	0.797	0.427
29	13.86	0.340	0.130	0.105	0.010	271	21	11.4	0.8	-0.9	0.2	1.208	0.006	5.6	2.6	1.280	0.000
	Total	0.388	0.203	0.083	0.042	273	51	10.5	3.1	-0.2	1.3	1.221	0.013	12.4	11.9	0.999	1.069

Table 8.1 Average and standard deviation of measured ambient conditions in 135 m during test

Height 120.0 m	Depen-dency [-]	shear exponent alpha 135m-100m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9	4.14	-0.041	0.320	0.091	0.061	170.9	73.1	13.1	2.5	0.5	2.6	1.218	0.013	13.9	11.2	1.706	2.232
10	4.48	0.185	0.219	0.079	0.047	164.0	64.8	12.9	3.5	0.4	2.2	1.216	0.011	14.2	12.4	1.654	1.453
11	5.00	0.356	0.293	0.081	0.047	242.1	65.6	12.0	3.2	0.5	2.0	1.217	0.011	17.6	18.0	1.559	1.210
12	5.48	0.287	0.241	0.085	0.062	277.6	61.4	10.8	3.0	0.3	2.0	1.223	0.012	17.8	17.3	0.839	1.371
13	5.98	0.314	0.246	0.098	0.060	290.3	55.1	10.6	3.3	0.1	1.9	1.224	0.016	16.9	17.4	0.993	1.190
14	6.45	0.375	0.200	0.098	0.046	275.9	59.3	10.6	3.0	-0.5	1.5	1.225	0.016	13.0	13.7	0.862	1.002
15	6.98	0.371	0.197	0.091	0.041	261.3	53.5	9.8	3.4	-0.6	0.9	1.226	0.016	9.7	8.7	0.904	1.244
16	7.45	0.442	0.159	0.080	0.032	259.0	44.4	9.6	3.0	-0.6	0.7	1.226	0.014	11.3	8.4	0.966	0.776
17	7.98	0.447	0.165	0.083	0.035	266.7	43.6	9.9	3.3	-0.3	1.0	1.222	0.014	13.1	7.4	1.112	1.004
18	8.52	0.422	0.161	0.086	0.040	265.7	39.0	10.0	3.2	-0.2	1.0	1.221	0.014	12.5	7.2	1.001	0.769
19	9.01	0.457	0.139	0.075	0.028	266.3	44.2	10.7	3.2	-0.3	0.7	1.217	0.014	11.8	5.9	1.102	0.856
20	9.49	0.412	0.129	0.080	0.034	259.9	34.3	9.8	3.3	-0.2	0.9	1.222	0.014	11.0	7.0	1.266	0.642
21	9.98	0.409	0.124	0.087	0.033	268.3	33.5	9.8	2.4	-0.2	0.9	1.223	0.010	9.8	5.2	1.036	0.741
22	10.50	0.415	0.086	0.090	0.035	267.5	48.2	10.2	2.8	-0.4	0.7	1.221	0.011	7.6	4.1	1.156	1.000
23	10.97	0.413	0.117	0.097	0.042	267.8	51.4	10.5	3.1	-0.6	0.7	1.219	0.014	6.6	4.0	1.057	1.039
24	11.49	0.357	0.140	0.129	0.027	283.8	19.6	10.5	2.7	-0.8	0.5	1.216	0.012	5.1	2.5	0.739	0.897
25	12.03	0.368	0.126	0.120	0.035	278.8	20.4	10.2	3.0	-0.7	0.5	1.215	0.013	6.5	2.9	0.998	0.327
26	12.47	0.341	0.077	0.113	0.009	270.2	27.6	12.0	1.4	-0.8	0.4	1.206	0.008	5.7	1.8	0.579	0.609
27	13.03	0.398	0.035	0.111	0.013	267.7	21.2	10.0	2.6	-0.8	0.0	1.216	0.011	5.7	0.2	1.361	0.115
	Total	0.383	0.194	0.088	0.042	265.4	50.2	10.4	3.2	-0.2	1.3	1.221	0.014	12.0	10.7	1.097	1.038

Table 8.2 Average and standard deviation of measured ambient conditions in 120 m during test

Height 100.0 m	Depen-dency [-]	shear exponent alpha 120m-80m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9	4.16	-0.128	0.231	0.080	0.058	244.6	80.8	13.0	2.7	0.7	2.3	1.217	0.009	16.4	14.9	0.333	2.124
10	4.51	0.160	0.239	0.074	0.048	211.8	75.9	12.8	3.4	0.8	2.2	1.215	0.011	20.2	16.4	0.512	1.577
11	5.00	0.279	0.230	0.074	0.056	274.3	74.5	11.8	3.4	0.6	2.0	1.219	0.012	18.9	16.4	0.288	1.547
12	5.49	0.347	0.226	0.094	0.065	293.7	59.6	10.5	3.2	0.3	1.9	1.225	0.015	19.2	18.0	-0.296	1.297
13	5.99	0.320	0.224	0.098	0.055	295.3	51.2	10.5	2.9	-0.1	1.6	1.224	0.014	15.5	14.3	-0.436	1.227
14	6.51	0.367	0.193	0.101	0.041	276.9	50.5	10.1	3.2	-0.5	1.2	1.224	0.015	10.8	10.0	-0.613	1.151
15	7.01	0.380	0.162	0.088	0.049	272.3	51.2	10.3	3.1	-0.3	1.1	1.223	0.014	13.0	9.7	-0.557	1.264
16	7.51	0.421	0.150	0.098	0.044	271.2	42.8	10.2	3.3	-0.2	1.0	1.220	0.013	13.3	8.1	-0.644	1.153
17	8.01	0.457	0.141	0.092	0.038	269.3	44.1	10.9	3.1	-0.3	0.9	1.217	0.014	11.8	6.9	-0.567	1.143
18	8.51	0.423	0.110	0.105	0.039	275.7	37.0	10.4	2.9	-0.4	0.9	1.219	0.012	10.5	6.9	-0.724	0.878
19	9.00	0.403	0.106	0.097	0.035	267.6	39.3	10.1	2.9	-0.3	0.9	1.220	0.012	10.5	6.7	-0.622	0.892
20	9.50	0.402	0.096	0.097	0.042	263.6	43.2	10.1	2.6	-0.2	0.9	1.223	0.011	8.2	4.4	-0.633	0.892
21	9.93	0.384	0.100	0.119	0.033	279.8	40.8	10.4	2.7	-0.6	0.7	1.218	0.011	6.5	4.1	-0.575	0.884
22	10.49	0.386	0.125	0.126	0.032	290.4	41.2	10.0	3.0	-0.6	0.5	1.219	0.010	6.1	3.1	-0.453	1.103
23	11.00	0.360	0.130	0.142	0.033	276.1	28.6	11.3	2.2	-0.8	0.5	1.211	0.010	5.6	3.0	-0.872	0.640
24	11.48	0.278	0.133	0.141	0.025	277.9	26.0	11.9	2.4	-1.0	0.5	1.208	0.011	5.1	2.4	-1.263	0.432
25	12.02	0.331	0.079	0.122	0.016	260.3	17.3	11.4	2.1	-0.9	0.3	1.209	0.010	5.6	1.5	-1.156	0.524
	Total	0.350	0.200	0.097	0.048	274.552	52.642	10.751	3.141	-0.120	1.430	1.220	0.013	12.960	11.897	-0.393	1.269

Table 8.3 Average and standard deviation of measured ambient conditions in 100 m during test

Height 80.0 m	Depen-dency [-]	shear exponent alpha 100m-60m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9	4.19	0.046	0.061	0.081	0.045	284.8	62.2	12.0	3.2	0.6	2.4	1.221	0.011	23.5	24.7	-0.225	2.234
10	4.53	0.137	0.210	0.070	0.053	196.8	83.0	13.1	3.2	1.1	2.2	1.214	0.010	21.6	16.1	0.693	1.557
11	4.99	0.283	0.227	0.091	0.068	283.0	67.6	11.3	3.2	0.7	2.1	1.222	0.013	20.6	17.8	0.206	1.494
12	5.52	0.347	0.177	0.102	0.049	280.0	53.2	10.1	3.5	-0.2	1.4	1.225	0.016	15.2	14.2	-0.562	1.157
13	5.98	0.319	0.179	0.112	0.055	285.7	49.8	10.5	3.0	-0.3	1.4	1.223	0.014	11.6	11.0	-0.504	1.318
14	6.49	0.372	0.167	0.103	0.044	278.1	46.4	10.3	3.1	-0.3	1.2	1.223	0.014	12.2	9.3	-0.565	1.074
15	7.00	0.434	0.135	0.099	0.045	273.9	39.2	10.1	3.2	0.0	1.1	1.219	0.014	13.9	8.5	-0.645	1.092
16	7.50	0.410	0.137	0.108	0.043	275.7	39.0	10.1	3.1	-0.3	1.0	1.220	0.012	11.5	7.3	-0.817	1.001
17	8.01	0.391	0.113	0.115	0.042	272.4	34.4	10.3	2.7	-0.4	0.9	1.219	0.011	9.9	6.6	-0.755	0.837
18	8.51	0.405	0.103	0.101	0.041	267.3	42.4	9.8	2.6	-0.1	1.0	1.222	0.011	9.2	4.9	-0.650	0.834
19	8.97	0.377	0.089	0.125	0.038	276.7	34.8	10.4	2.2	-0.5	0.7	1.220	0.009	7.3	3.8	-0.842	0.660
20	9.44	0.352	0.134	0.135	0.032	285.7	27.3	9.6	3.1	-0.6	0.5	1.220	0.013	6.5	3.7	-0.524	0.702
21	9.97	0.319	0.099	0.159	0.024	286.7	16.8	10.7	2.2	-0.8	0.4	1.216	0.008	4.8	2.5	-0.992	0.486
22	10.50	0.256	0.101	0.148	0.027	273.1	23.4	11.9	2.0	-1.0	0.4	1.208	0.009	5.3	2.5	-1.097	0.314
23	11.04	0.241	0.127	0.145	0.026	271.5	21.4	11.7	2.4	-1.1	0.4	1.209	0.010	4.5	2.6	-1.213	0.439
24	11.39	0.218	0.087	0.139	0.030	254.1	10.3	12.8	1.6	-1.1	0.5	1.204	0.008	4.9	1.3	-1.193	0.520
	Total	0.338	0.179	0.106	0.051	276.072	49.578	10.642	3.113	-0.102	1.452	1.220	0.013	12.992	12.044	-0.444	1.244

Table 8.4 Average and standard deviation of measured ambient conditions in 80 m during test

Height 60.0 m	Depen-dency [-]	shear exponent alpha 80m-40m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9.00	4.19	0.090	0.081	0.116	0.046	207.3	75.8	12.4	3.9	0.1	2.6	1.216	0.012	21.09	27.15	1.165	2.413
10.00	4.55	0.171	0.132	0.115	0.076	243.4	68.5	11.4	3.5	0.5	2.5	1.222	0.016	18.82	20.66	0.903	1.536
11.00	5.05	0.281	0.147	0.121	0.055	256.6	64.3	10.5	3.8	-0.2	1.7	1.223	0.017	14.27	14.33	0.203	1.351
12.00	5.50	0.360	0.175	0.112	0.055	284.6	51.7	10.5	3.1	-0.1	1.5	1.222	0.014	13.24	12.94	-0.191	0.883
13.00	6.02	0.398	0.151	0.110	0.045	271.5	44.9	10.4	3.3	-0.1	1.3	1.221	0.014	13.12	9.21	-0.071	0.906
14.00	6.46	0.363	0.151	0.124	0.043	273.7	36.2	9.7	3.2	-0.3	1.0	1.222	0.013	11.67	7.64	-0.100	0.698
15.00	7.02	0.374	0.135	0.120	0.045	275.3	37.4	9.9	2.8	-0.3	1.0	1.221	0.012	9.81	5.87	-0.258	0.780
16.00	7.50	0.356	0.124	0.127	0.045	270.5	41.6	10.5	2.5	-0.4	0.9	1.219	0.011	8.09	4.37	-0.234	0.790
17.00	7.97	0.309	0.088	0.144	0.027	269.0	41.3	10.8	2.6	-0.7	0.4	1.219	0.010	6.53	3.50	-0.023	0.862
18.00	8.49	0.291	0.081	0.158	0.028	279.1	34.4	10.3	2.7	-0.7	0.4	1.219	0.011	6.26	2.96	-0.012	0.667
19.00	9.03	0.249	0.075	0.167	0.026	282.4	14.4	10.5	2.5	-0.8	0.4	1.216	0.010	4.83	3.05	-0.085	0.388
20.00	9.52	0.216	0.070	0.154	0.034	274.3	28.2	11.6	2.5	-1.0	0.4	1.211	0.012	4.73	2.89	-0.349	0.535
21.00	9.98	0.208	0.070	0.153	0.019	272.3	20.7	12.2	1.3	-1.1	0.4	1.207	0.007	4.38	2.31	-0.341	0.327
22.00	10.45	0.222	0.066	0.145	0.026	257.9	16.6	11.9	1.5	-0.9	0.3	1.208	0.007	5.46	2.29	-0.634	0.401
23.00	10.97	0.118	0.029	0.170	0.031	264.0	17.1	14.2	1.0	-1.6	0.1	1.200	0.009	3.27	1.27	-0.959	0.816
	Total	0.326	0.153	0.125	0.049	272.171	46.606	10.513	3.101	-0.302	1.308	1.220	0.014	11.128	10.859	-0.043	1.020

Table 8.5 Average and standard deviation of measured ambient conditions in 60 m during test

Height 40.0 m	Depen-dency [-]	shear exponent alpha 60m-40m		Turbulence Intensity I		Wind direction		Air temperature T at 131 m		T difference 131m-18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
Bin-No.	Windspeed [m/s]	avg [-]	std [-]	avg [-]	std [-]	avg [deg]	std [deg]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m3]	std [kg/m3]	avg [deg]	std [deg]	avg [deg]	std [deg]
9.00	4.13	0.404	0.223	0.117	0.056	275.3	55.3	10.7	3.2	0.2	1.7	1.222	0.014	16.53	15.72	0.183	1.225
10.00	4.52	0.382	0.209	0.116	0.061	269.9	55.5	10.5	3.3	0.3	1.8	1.222	0.014	16.98	16.28	0.232	1.296
11.00	5.02	0.351	0.150	0.136	0.046	270.3	55.1	10.2	3.8	-0.4	1.2	1.221	0.016	11.63	10.11	-0.103	0.995
12.00	5.50	0.356	0.167	0.136	0.052	277.3	44.2	9.7	3.3	-0.3	1.1	1.222	0.014	11.04	7.81	-0.191	0.831
13.00	6.01	0.317	0.126	0.138	0.033	274.0	36.7	9.7	2.7	-0.5	0.7	1.222	0.013	8.85	4.71	-0.231	0.780
14.00	6.49	0.277	0.097	0.151	0.032	268.3	38.2	10.9	2.4	-0.8	0.4	1.219	0.012	6.86	3.49	-0.195	0.900
15.00	6.98	0.269	0.084	0.163	0.035	273.5	40.5	11.2	2.1	-0.9	0.4	1.217	0.008	6.26	2.95	-0.179	0.830
16.00	7.46	0.259	0.062	0.165	0.024	277.6	31.4	10.7	2.5	-0.7	0.4	1.217	0.011	5.41	2.79	0.007	0.765
17.00	8.02	0.232	0.059	0.172	0.024	284.8	22.9	10.8	2.4	-0.8	0.4	1.215	0.011	5.36	2.73	-0.199	0.699
18.00	8.50	0.193	0.054	0.183	0.030	286.4	24.5	11.6	2.2	-1.1	0.3	1.212	0.010	4.42	2.73	-0.040	0.705
19.00	8.99	0.182	0.045	0.170	0.029	275.5	27.5	12.3	1.6	-1.2	0.3	1.208	0.008	3.67	2.59	-0.183	0.661
20.00	9.51	0.186	0.055	0.171	0.036	273.5	27.1	12.2	1.4	-1.2	0.3	1.208	0.008	3.88	2.15	-0.448	0.474
21.00	9.95	0.161	0.068	0.174	0.039	279.7	26.4	12.1	1.9	-1.3	0.3	1.210	0.008	3.53	2.02	-0.830	0.283
22.00	10.44	0.125	0.039	0.175	0.021	269.2	19.3	13.5	1.2	-1.5	0.2	1.204	0.009	3.48	2.06	-0.382	0.943
23.00	10.92	0.148	0.048	0.157	0.020	270.1	22.7	12.7	1.6	-1.2	0.2	1.205	0.008	3.12	1.38	-0.149	0.331
	Total	0.307	0.162	0.144	0.048	274.504	43.604	10.697	3.006	-0.470	1.186	1.219	0.014	9.866	10.390	-0.077	0.988

Table 8.6 Average and standard deviation of measured ambient conditions in 40 m during test

8.2 Ambient conditions dependent on wind direction

This chapter presents detailed ambient conditions during test dependent on wind direction.

Height 135.0 m	Dependency [-]	shear exponent α 135m-100m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
1	2.7	0.193	0.247	0.101	0.048	11.0	4.4	-0.7	1.3	1.221	0.009	13.2	17.6	-0.72	1.41
2	7.5	0.457	0.284	0.099	0.034	8.5	3.1	-0.2	1.0	1.229	0.008	2.5	8.6	-1.21	0.82
4	16.8	0.513	0.268	0.097	0.024	7.1	0.4	0.2	0.4	1.234	0.006	7.8	14.1	-0.81	0.67
5	22.7	0.182	0.135	0.058	0.010	10.8	4.5	-0.9	1.1	1.225	0.015	8.5	5.0	-1.10	0.37
28	137.4	0.414	0.285	0.086	0.043	13.2	3.1	-0.4	1.5	1.217	0.015	10.3	6.5	1.70	1.17
29	142.4	0.390	0.201	0.070	0.040	15.0	1.8	-0.2	1.6	1.207	0.011	10.1	6.1	1.75	0.81
30	147.6	0.499	0.240	0.066	0.042	15.8	1.5	0.1	1.5	1.201	0.009	7.3	5.2	2.52	0.88
31	152.8	0.321	0.366	0.098	0.053	15.8	1.4	-0.5	1.6	1.202	0.008	4.4	6.0	2.84	1.26
32	157.4	0.263	0.338	0.082	0.049	15.4	1.1	0.4	2.1	1.204	0.006	11.2	11.9	2.61	0.96
33	161.9	0.258	0.312	0.071	0.033	14.7	0.7	0.4	1.9	1.206	0.003	9.3	11.6	2.78	0.45
49	243.5	0.372	0.139	0.086	0.037	10.2	2.5	-0.8	0.7	1.223	0.014	9.6	6.5	1.28	0.63
50	247.5	0.386	0.155	0.075	0.034	9.7	2.8	-0.6	0.7	1.225	0.016	9.5	5.7	1.21	0.44
51	252.4	0.409	0.174	0.074	0.031	10.1	2.7	-0.5	0.8	1.224	0.014	10.4	7.7	1.10	0.59
52	257.3	0.416	0.175	0.085	0.031	9.8	2.5	-0.5	0.8	1.224	0.015	8.6	14.9	1.07	0.57
53	262.3	0.381	0.175	0.093	0.047	8.9	2.6	-0.2	1.3	1.230	0.015	12.5	10.1	1.11	0.55
54	267.7	0.335	0.214	0.088	0.044	8.9	2.4	-0.2	1.4	1.231	0.013	12.5	11.2	0.99	0.79
55	272.4	0.390	0.210	0.077	0.032	9.8	2.5	0.0	1.4	1.225	0.014	14.6	11.3	1.32	0.54
56	277.3	0.365	0.232	0.084	0.046	10.4	2.6	-0.3	1.2	1.220	0.011	11.4	8.6	1.75	1.04
57	282.3	0.378	0.143	0.103	0.047	11.1	2.8	-0.8	0.7	1.217	0.010	7.3	6.4	0.94	1.00
58	287.6	0.344	0.150	0.089	0.051	8.9	3.1	-0.2	1.3	1.225	0.010	14.9	12.1	1.33	0.66
59	292.4	0.445	0.125	0.079	0.042	8.6	2.6	0.1	1.2	1.224	0.011	17.8	12.1	1.12	0.44
60	297.9	0.424	0.175	0.070	0.045	9.6	2.7	0.4	1.6	1.223	0.008	20.5	15.1	0.73	0.73
61	302.5	0.373	0.224	0.074	0.036	9.5	2.4	0.3	1.2	1.221	0.008	15.3	12.1	0.55	0.53
62	307.1	0.409	0.269	0.072	0.039	10.3	2.4	0.8	1.7	1.221	0.007	21.5	18.9	0.42	0.51
63	312.5	0.327	0.200	0.063	0.052	10.6	2.0	0.9	1.7	1.222	0.004	25.5	18.0	0.17	0.46
64	317.5	0.420	0.152	0.080	0.041	11.3	1.5	0.0	1.2	1.219	0.005	17.6	15.0	0.32	0.77
65	322.2	0.415	0.169	0.109	0.050	10.9	2.3	-0.8	0.8	1.219	0.008	9.8	9.9	0.16	0.58
66	327.6	0.289	0.161	0.104	0.058	9.5	2.5	-0.1	1.3	1.221	0.007	20.0	16.7	0.24	1.94
67	331.9	0.354	0.182	0.120	0.054	10.9	1.8	-0.8	0.8	1.218	0.008	12.0	11.9	0.24	0.86
68	337.5	0.413	0.189	0.114	0.047	10.7	1.9	-0.7	1.0	1.218	0.007	11.7	13.1	-0.25	1.01
69	342.5	0.455	0.256	0.104	0.054	9.9	1.4	-0.8	0.8	1.220	0.009	10.0	12.1	-0.44	1.03
70	347.3	0.372	0.160	0.091	0.053	8.2	1.4	-0.5	1.0	1.228	0.006	12.7	11.8	-0.32	1.07
71	352.2	0.454	0.215	0.079	0.041	8.1	1.8	0.1	1.1	1.226	0.005	15.0	12.5	-0.36	0.80
72	356.7	0.384	0.219	0.082	0.034	8.4	2.8	0.3	0.9	1.224	0.006	11.2	9.8	-0.30	0.55
	Total	0.388	0.203	0.083	0.042	10.508	3.058	-0.248	1.271	1.221	0.013	12.426	11.906	0.999	1.069

Table 8.7 Average and standard deviation of measured ambient conditions in 135 m during test

Height 119.9 m	Dependency [-]	shear exponent α 135m-100m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
1	1.3	0.062	0.129	0.112	0.051	12.6	4.1	-1.0	1.5	1.219	0.011	11.2	11.8	-0.96	1.91
2	7.4	0.348	0.295	0.109	0.041	9.0	3.9	-0.5	1.0	1.227	0.009	4.1	8.8	-1.41	0.97
4	17.0	0.388	0.282	0.099	0.009	6.8	0.5	-0.2	0.2	1.236	0.009	11.1	10.5	-0.83	1.02
28	137.3	0.380	0.267	0.088	0.040	14.3	2.6	-0.3	1.6	1.211	0.014	10.2	6.7	1.64	0.62
29	142.6	0.366	0.341	0.072	0.036	15.6	1.6	0.1	2.0	1.203	0.010	9.7	6.0	1.90	0.83
30	147.2	0.408	0.306	0.071	0.043	15.7	1.6	0.3	1.7	1.202	0.010	7.9	5.9	2.49	0.81
31	153.2	0.210	0.234	0.092	0.052	15.8	1.4	-0.2	1.9	1.202	0.008	4.9	6.9	2.59	1.14
32	157.0	0.244	0.232	0.072	0.046	15.3	0.9	0.8	2.1	1.205	0.005	13.5	12.7	2.89	0.80
33	161.6	0.271	0.257	0.080	0.033	14.8	0.7	0.2	2.0	1.206	0.003	10.8	13.5	2.77	0.45
49	243.4	0.375	0.128	0.087	0.038	9.3	3.0	-0.7	0.7	1.226	0.016	9.6	5.5	1.22	0.56
50	247.3	0.398	0.168	0.080	0.035	9.9	2.5	-0.6	0.7	1.225	0.014	9.7	6.9	1.22	0.50
51	252.1	0.407	0.125	0.082	0.028	10.0	2.7	-0.6	0.8	1.224	0.015	10.4	5.8	0.95	0.50
52	257.1	0.382	0.160	0.093	0.037	9.4	2.7	-0.4	1.1	1.226	0.015	10.9	7.6	1.10	0.57
53	262.4	0.429	0.164	0.097	0.048	9.2	2.5	-0.3	1.1	1.229	0.012	11.8	11.6	0.97	0.71
54	267.7	0.343	0.256	0.094	0.043	9.4	2.4	-0.2	1.4	1.230	0.014	13.6	11.0	1.21	0.67
55	272.4	0.351	0.248	0.085	0.042	10.1	2.5	-0.1	1.5	1.222	0.011	12.3	9.9	1.72	1.03
56	277.7	0.370	0.135	0.098	0.048	11.2	2.4	-0.7	0.6	1.216	0.009	9.0	6.6	1.25	0.93
57	282.6	0.377	0.134	0.098	0.041	10.3	3.1	-0.5	1.2	1.220	0.011	10.4	9.9	1.12	0.77
58	287.8	0.385	0.157	0.089	0.054	8.4	2.8	0.0	1.0	1.226	0.010	16.1	11.9	1.29	0.66
59	292.3	0.427	0.114	0.091	0.045	8.8	2.5	0.0	1.3	1.223	0.010	17.0	13.3	1.02	0.40
60	297.5	0.414	0.205	0.081	0.044	9.5	2.4	0.5	1.6	1.222	0.008	20.2	15.4	0.62	0.69
61	302.5	0.467	0.219	0.078	0.041	9.9	2.3	0.7	1.7	1.221	0.007	20.7	18.4	0.42	0.57
62	307.2	0.390	0.210	0.083	0.038	10.1	2.3	0.3	1.5	1.221	0.008	16.9	16.9	0.22	0.58
66	329.0	0.318	0.108	0.148	0.061	11.3	1.4	-1.0	0.4	1.218	0.009	9.9	5.8	0.93	2.08
67	333.3	0.381	0.219	0.116	0.044	11.1	1.6	-0.6	1.1	1.217	0.006	12.7	14.4	0.05	1.00
68	338.0	0.464	0.127	0.127	0.054	10.4	1.7	-0.7	0.7	1.217	0.008	10.0	10.2	0.00	0.77
69	342.7	0.383	0.208	0.117	0.061	9.5	1.5	-1.0	0.7	1.223	0.009	8.0	8.2	-0.63	1.03
70	347.7	0.363	0.143	0.094	0.060	8.1	1.2	-0.4	1.1	1.228	0.005	12.0	10.1	-0.36	1.15
71	352.6	0.427	0.152	0.082	0.023	8.4	1.8	0.6	0.9	1.224	0.005	12.5	5.7	-0.26	0.62
72	356.0	0.378	0.249	0.089	0.037	8.5	3.1	0.0	0.8	1.225	0.007	9.8	11.0	-0.24	0.64
	Total	0.383	0.194	0.088	0.042	10.441	3.178	-0.226	1.303	1.221	0.014	11.987	10.699	1.097	1.038

Table 8.8 Average and standard deviation of measured ambient conditions in 130 m during test

Height 99.9 m	Dependency [-]	shear exponent α 120m-80m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
1	3.2	0.139	0.253	0.106	0.041	13.1	3.6	-1.2	1.3	1.218	0.010	4.9	6.8	-0.49	1.39
2	7.6	0.401	0.270	0.120	0.046	9.1	3.8	-0.4	1.1	1.227	0.009	4.9	10.2	-0.66	1.33
4	18.3	0.298	0.265	0.075	0.029	8.2	3.4	-0.4	0.7	1.233	0.013	11.6	7.5	-0.17	0.73
6	28.1	0.176	0.143	0.045	0.034	13.5	2.6	-0.5	1.0	1.216	0.006	10.6	5.9	0.37	0.52
27	133.9	0.247	0.209	0.111	0.065	12.0	5.3	-0.4	1.5	1.222	0.026	9.6	8.3	1.46	1.07
28	137.6	0.304	0.203	0.096	0.050	13.9	4.4	-0.1	2.0	1.212	0.022	8.6	5.6	1.69	0.54
29	141.9	0.326	0.322	0.089	0.035	16.1	1.3	0.1	2.0	1.199	0.008	8.2	3.7	1.85	1.13
30	147.3	0.240	0.292	0.094	0.047	15.4	3.4	0.3	2.4	1.204	0.017	8.6	8.4	2.11	0.86
31	152.8	0.219	0.179	0.086	0.057	15.4	1.1	0.8	2.3	1.205	0.006	13.1	12.0	2.05	1.20
32	157.4	0.181	0.257	0.079	0.050	15.2	1.1	0.7	2.1	1.205	0.006	10.7	14.3	1.59	0.75
33	161.5	0.102	0.290	0.075	0.045	14.9	0.7	1.1	2.2	1.207	0.004	18.1	16.8	1.51	0.64
34	165.4	0.107	0.269	0.102	0.048	14.6	0.9	1.1	2.6	1.208	0.005	12.6	13.1	1.60	0.46
49	243.4	0.359	0.105	0.093	0.034	10.3	2.3	-0.7	0.6	1.221	0.014	9.2	5.4	-1.19	0.55
50	247.2	0.388	0.117	0.096	0.031	9.9	2.7	-0.6	0.7	1.225	0.015	9.4	6.0	-1.17	0.40
51	252.6	0.376	0.124	0.096	0.035	10.1	2.6	-0.4	1.0	1.221	0.015	11.0	8.2	-1.30	0.62
52	257.0	0.383	0.178	0.104	0.043	9.2	2.7	-0.4	1.2	1.231	0.016	12.3	10.2	-1.17	0.61
53	262.6	0.361	0.197	0.116	0.051	10.0	2.4	-0.5	1.1	1.224	0.011	8.1	9.1	-0.89	0.58
54	267.6	0.299	0.229	0.092	0.051	9.9	2.3	0.2	1.8	1.226	0.012	14.0	10.8	-0.90	0.87
55	272.7	0.350	0.202	0.093	0.045	10.3	2.7	-0.1	1.5	1.220	0.012	12.5	10.5	-0.50	0.70
56	277.9	0.377	0.163	0.101	0.047	10.7	3.0	-0.6	0.7	1.218	0.010	10.0	8.1	-0.67	0.87
57	282.7	0.372	0.142	0.094	0.050	9.1	3.2	-0.1	1.1	1.223	0.010	16.5	13.1	-0.77	0.39
58	287.6	0.434	0.160	0.097	0.058	9.3	2.7	0.3	1.6	1.225	0.011	19.0	15.1	-0.47	0.58
59	292.8	0.434	0.177	0.085	0.043	9.9	2.3	0.7	1.8	1.221	0.007	22.5	17.6	-0.76	0.50
60	297.5	0.428	0.213	0.093	0.049	9.6	2.4	0.5	1.5	1.222	0.007	19.7	15.7	-0.85	0.72
61	302.5	0.291	0.276	0.094	0.051	10.4	2.5	0.3	1.2	1.220	0.007	14.4	11.9	-0.87	0.85
62	307.4	0.382	0.170	0.070	0.048	10.6	2.2	0.7	1.4	1.221	0.006	21.0	17.0	-1.00	0.47
63	312.8	0.382	0.188	0.096	0.061	11.1	1.8	0.1	1.3	1.220	0.005	19.4	15.6	-0.64	0.70
64	317.6	0.314	0.163	0.121	0.049	10.9	2.3	-0.5	1.0	1.218	0.006	13.2	12.2	-0.69	0.73
65	321.7	0.358	0.141	0.135	0.062	10.0	2.7	-0.7	1.0	1.221	0.009	12.6	13.2	-0.49	1.02
66	326.9	0.341	0.194	0.122	0.056	10.9	2.1	-0.8	0.6	1.219	0.008	11.7	12.3	-0.39	1.72
67	332.7	0.313	0.170	0.157	0.060	11.6	1.1	-1.1	0.7	1.216	0.006	6.7	8.5	-0.36	1.00
68	337.1	0.393	0.214	0.122	0.046	9.9	2.0	-0.9	0.7	1.220	0.009	9.6	7.8	-0.64	0.95
69	342.8	0.435	0.172	0.112	0.065	8.8	1.7	-0.7	0.9	1.224	0.008	11.2	10.7	-0.74	0.62
70	347.5	0.403	0.182	0.095	0.053	8.5	1.7	-0.2	1.1	1.226	0.005	10.6	8.1	-0.72	1.07
71	352.3	0.439	0.200	0.086	0.036	8.3	2.0	0.3	1.0	1.224	0.005	11.3	7.6	-0.11	1.02
72	357.4	0.328	0.252	0.113	0.034	9.7	4.1	-0.2	1.1	1.224	0.011	7.0	12.2	0.01	0.34
	Total	0.350	0.200	0.097	0.048	10.751	3.141	-0.120	1.430	1.220	0.013	12.960	11.897	-0.393	1.269

Table 8.9 Average and standard deviation of measured ambient conditions in 100 m during test

Height 81.9 m	Dependency [-]	shear exponent α 100m-60m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
5	23.2	0.213	0.104	0.036	0.030	12.9	2.6	0.0	0.9	1.218	0.005	11.2	4.6	0.3	0.1
6	28.4	0.280	0.163	0.044	0.042	12.8	3.1	0.0	1.1	1.218	0.007	8.1	4.7	0.8	0.7
27	134.5	0.267	0.179	0.158	0.028	8.8	6.9	-1.3	0.2	1.237	0.033	3.9	2.8	1.9	1.1
28	137.7	0.360	0.143	0.108	0.042	15.5	3.0	-0.3	1.7	1.203	0.016	7.7	3.6	1.8	0.5
29	141.8	0.184	0.290	0.086	0.041	15.9	1.2	0.7	2.4	1.201	0.008	9.9	6.2	1.9	1.2
30	147.4	0.075	0.241	0.080	0.055	15.2	2.8	1.5	2.4	1.206	0.014	16.4	13.7	2.3	0.7
31	152.5	0.155	0.154	0.116	0.048	16.0	1.0	-0.3	2.0	1.201	0.006	10.7	15.2	1.6	1.4
32	156.3	0.204	0.165	0.081	0.053	15.2	0.8	1.1	2.4	1.205	0.005	15.5	14.5	1.6	0.6
49	243.7	0.344	0.108	0.102	0.031	9.6	2.6	-0.6	0.8	1.226	0.014	10.2	7.1	-1.2	0.5
50	247.3	0.352	0.117	0.101	0.031	10.1	2.8	-0.6	0.9	1.223	0.016	9.4	6.8	-1.2	0.5
51	252.4	0.336	0.127	0.107	0.038	9.7	2.4	-0.4	1.0	1.225	0.016	10.4	7.6	-1.1	0.7
52	257.5	0.340	0.178	0.109	0.044	10.1	2.6	-0.5	1.3	1.225	0.015	9.0	8.2	-1.1	0.6
53	262.4	0.291	0.199	0.104	0.055	10.1	2.1	0.1	1.8	1.226	0.011	12.9	12.3	-0.9	0.7
54	267.5	0.322	0.212	0.107	0.055	10.0	2.7	-0.1	1.4	1.222	0.012	12.1	9.6	-0.6	0.7
55	272.2	0.376	0.152	0.098	0.043	10.5	2.5	-0.3	0.9	1.220	0.012	15.6	14.4	-0.6	0.8
56	277.6	0.359	0.174	0.099	0.048	9.6	3.1	0.2	1.6	1.222	0.010	17.2	14.2	-0.7	0.7
57	282.4	0.305	0.219	0.098	0.057	10.0	2.8	0.7	1.9	1.223	0.011	22.0	19.6	-0.7	0.5
58	287.6	0.371	0.153	0.108	0.052	9.1	2.8	0.3	1.4	1.224	0.009	18.5	15.5	-0.7	0.6
59	292.4	0.418	0.116	0.119	0.051	9.2	2.4	-0.1	1.1	1.221	0.008	13.9	10.3	-0.9	0.4
60	297.5	0.386	0.188	0.091	0.055	10.2	2.4	0.6	1.4	1.221	0.007	19.3	15.4	-1.1	0.4
61	302.4	0.413	0.129	0.106	0.054	10.3	2.3	0.2	1.2	1.220	0.007	15.4	15.0	-0.7	0.8
62	307.4	0.354	0.203	0.081	0.066	10.9	2.1	0.7	1.3	1.221	0.005	21.0	14.2	-0.8	0.7
63	312.4	0.370	0.139	0.124	0.053	10.7	2.1	-0.4	0.9	1.218	0.005	14.3	11.8	-0.7	0.6
64	317.3	0.326	0.140	0.151	0.047	10.9	2.5	-1.0	0.8	1.218	0.008	8.6	9.8	-0.7	0.8
65	321.8	0.348	0.189	0.147	0.059	10.1	2.3	-1.0	0.7	1.222	0.010	11.1	11.3	-0.4	1.1
66	327.1	0.334	0.234	0.119	0.049	11.4	2.3	-0.7	0.7	1.216	0.004	13.2	11.2	0.0	2.2
67	333.0	0.395	0.168	0.152	0.062	10.6	2.0	-1.0	0.6	1.218	0.009	7.9	7.1	-0.6	0.7
68	337.3	0.372	0.217	0.120	0.044	9.6	2.1	-0.7	1.0	1.221	0.009	10.9	9.9	-0.8	1.1
69	342.8	0.474	0.143	0.122	0.076	8.6	0.8	-0.3	1.1	1.226	0.006	9.8	7.1	-0.6	0.4
70	346.9	0.430	0.190	0.104	0.051	8.5	1.7	-0.2	1.2	1.226	0.005	9.3	7.2	-0.8	1.1
71	351.5	0.440	0.188	0.095	0.042	9.1	2.4	-0.1	1.2	1.224	0.005	10.0	8.0	0.2	1.3
	Total	0.338	0.179	0.106	0.051	10.642	3.113	-0.102	1.452	1.220	0.013	12.992	12.044	-0.444	1.244

Table 8.10 Average and standard deviation of measured ambient conditions in 80 m during test

Height 60.9 m	Dependency [-]	shear exponent α 80m-40m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
27	133.9	0.224	0.160	0.128	0.057	11.2	6.4	-0.4	2.0	1.225	0.031	9.0	10.6	1.369	0.832
28	137.8	0.323	0.150	0.116	0.037	15.5	3.4	-0.3	1.5	1.203	0.017	8.5	7.1	1.521	0.758
29	142.4	0.218	0.153	0.085	0.054	14.8	3.6	1.0	2.3	1.208	0.018	12.2	9.6	2.128	1.626
30	147.0	0.191	0.136	0.145	0.051	16.5	1.1	-0.5	2.1	1.198	0.006	6.7	5.8	2.364	1.092
31	152.6	0.188	0.102	0.140	0.024	16.1	1.0	-1.5	0.5	1.199	0.004	2.6	2.3	1.883	1.476
32	157.3	0.264	0.133	0.139	0.022	15.4	1.1	-1.2	0.4	1.202	0.004	2.8	2.4	1.445	0.747
49	243.5	0.322	0.087	0.112	0.030	9.7	2.4	-0.6	0.9	1.226	0.013	9.5	5.8	-0.366	0.351
50	247.4	0.323	0.124	0.110	0.035	10.3	2.7	-0.5	1.0	1.221	0.018	9.3	7.2	-0.519	0.468
51	252.3	0.307	0.161	0.114	0.038	10.0	2.1	-0.4	1.2	1.225	0.015	9.6	8.5	-0.471	0.635
52	257.7	0.286	0.142	0.108	0.047	10.2	2.5	0.1	1.8	1.225	0.012	13.8	13.7	-0.288	0.548
53	262.2	0.231	0.135	0.101	0.043	9.9	2.5	0.1	1.9	1.226	0.011	15.5	14.6	-0.224	0.400
54	267.7	0.272	0.151	0.103	0.064	10.6	2.3	0.7	2.0	1.220	0.009	21.6	20.7	-0.054	0.541
55	272.4	0.330	0.176	0.107	0.041	9.1	2.9	0.4	1.5	1.224	0.012	18.8	17.1	0.211	0.454
56	277.3	0.333	0.171	0.122	0.042	9.8	3.2	-0.2	1.3	1.221	0.010	12.9	12.9	-0.116	0.554
57	282.3	0.316	0.130	0.142	0.037	10.2	2.7	-0.5	0.8	1.219	0.009	10.1	8.2	0.481	0.604
58	287.3	0.378	0.127	0.128	0.048	8.4	2.6	-0.2	0.9	1.222	0.010	13.4	8.8	0.044	0.552
59	292.3	0.389	0.125	0.133	0.052	9.3	2.5	-0.1	0.9	1.222	0.007	12.7	8.8	0.074	0.460
60	297.5	0.410	0.132	0.121	0.060	9.5	2.3	0.2	1.1	1.222	0.006	14.4	11.6	-0.342	0.510
61	302.0	0.360	0.144	0.138	0.048	9.8	2.4	-0.1	0.9	1.219	0.007	12.6	13.1	-0.403	0.562
	Total	0.326	0.153	0.125	0.049	10.513	3.101	-0.302	1.308	1.220	0.014	11.128	10.859	-0.043	1.020

Table 8.11 Average and standard deviation of measured ambient conditions in 60 m during test

Height 40.9 m	Dependency [-]	shear exponent α 60m-40m		Turbulence Intensity I		Air temperature T at 131 m		T difference 131m-18m		Air density		wind veer dir129m-dir38m		Flow Inclination angle	
Bin-No.	Direction [deg]	avg [-]	std [-]	avg [-]	std [-]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m³]	std [kg/m³]	avg [deg]	std [deg]	avg [deg]	std [deg]
27	133.1	0.320	0.114	0.124	0.056	13.3	5.8	-0.2	1.7	1.214	0.029	10.4	8.3	1.694	0.529
28	137.3	0.317	0.136	0.140	0.031	14.7	4.5	-0.7	1.0	1.206	0.023	6.5	5.1	1.433	0.737
29	142.8	0.267	0.164	0.137	0.030	15.1	4.5	-1.0	0.6	1.204	0.023	5.4	2.6	1.932	2.094
30	147.5	0.173	0.078	0.165	0.028	16.8	0.9	-1.5	0.3	1.196	0.005	4.0	2.9	1.891	1.042
31	152.9	0.170	0.094	0.153	0.023	16.1	1.0	-1.5	0.5	1.200	0.004	2.7	2.1	2.332	1.448
32	157.2	0.241	0.124	0.151	0.018	15.5	1.2	-1.2	0.4	1.202	0.005	2.7	2.6	1.283	0.844
49	243.3	0.358	0.153	0.121	0.044	10.3	2.3	-0.2	1.4	1.223	0.015	11.2	9.6	-0.410	0.483
50	247.4	0.232	0.105	0.132	0.040	11.0	2.5	-0.5	1.5	1.217	0.017	10.5	13.9	-0.382	0.528
51	252.3	0.236	0.139	0.115	0.046	10.8	2.6	-0.1	1.8	1.220	0.017	13.7	17.7	-0.322	0.649
52	257.4	0.255	0.133	0.120	0.045	9.7	2.8	-0.3	1.4	1.226	0.012	13.1	14.0	-0.348	0.544
53	262.6	0.252	0.162	0.130	0.033	10.2	2.4	-0.9	0.7	1.224	0.012	8.2	8.1	-0.267	0.441
54	267.8	0.330	0.145	0.132	0.044	9.6	3.0	-0.3	0.9	1.220	0.011	10.9	7.5	0.000	0.555
55	272.3	0.364	0.148	0.139	0.051	9.2	3.0	-0.2	0.9	1.223	0.012	10.8	8.4	0.167	0.676
56	277.4	0.308	0.157	0.139	0.037	10.7	2.7	-0.4	1.0	1.216	0.009	12.2	10.9	-0.003	0.428
57	282.7	0.324	0.179	0.132	0.042	9.9	2.9	-0.2	1.1	1.221	0.009	12.3	9.2	0.380	0.572
58	287.4	0.350	0.194	0.138	0.049	9.1	2.7	-0.1	1.1	1.221	0.008	14.5	12.3	-0.003	0.481
59	292.3	0.339	0.155	0.154	0.049	9.0	2.4	-0.3	0.9	1.222	0.006	11.2	10.8	-0.258	0.481
60	297.7	0.361	0.171	0.152	0.040	10.0	2.3	-0.3	0.7	1.218	0.008	8.2	4.5	-0.357	0.625
61	302.1	0.373	0.149	0.150	0.052	10.8	2.1	-0.3	0.8	1.217	0.008	8.1	5.1	-0.262	0.600
62	307.3	0.264	0.083	0.192	0.037	11.1	1.9	-1.0	0.4	1.216	0.007	7.9	3.9	-0.317	0.852
63	312.7	0.272	0.120	0.190	0.031	11.3	1.5	-0.9	0.6	1.216	0.005	6.7	5.8	-0.105	0.589
64	317.5	0.229	0.115	0.201	0.042	11.1	2.2	-1.3	0.3	1.217	0.010	4.4	3.1	-0.582	0.948
65	322.3	0.279	0.156	0.189	0.035	10.9	2.0	-1.2	0.5	1.218	0.008	4.8	4.5	0.227	1.843
66	327.9	0.363	0.219	0.180	0.035	11.3	1.5	-0.9	1.0	1.216	0.006	6.7	7.4	-0.174	1.091
67	333.3	0.444	0.231	0.168	0.052	10.1	1.7	-0.6	0.9	1.221	0.008	8.7	5.5	-0.606	0.591
68	337.1	0.410	0.241	0.170	0.039	9.6	1.8	-0.7	1.1	1.223	0.007	7.9	6.4	-0.735	0.795
69	342.4	0.501	0.148	0.160	0.064	8.3	0.4	-0.1	1.1	1.226	0.003	8.5	4.0	-0.909	0.712
70	346.6	0.388	0.166	0.180	0.040	8.8	0.8	-0.8	1.1	1.225	0.006	4.3	5.0	-1.562	1.373
	Total	0.307	0.162	0.144	0.048	10.697	3.006	-0.470	1.186	1.219	0.014	9.866	10.390	-0.077	0.988

Table 8.12 Average and standard deviation of measured ambient conditions in 40 m during test

8.3 Accuracy in Terms of the Horizontal Wind Speed Component without wind speed limitation

This chapter represents the results of the comparison of cup anemometer measurement and measurement of the RSD in terms of the horizontal wind speed component. It is similar to chapter 4.2 with the difference that no wind speed filter has been applied.

8.3.1 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 135 m Measurement Height

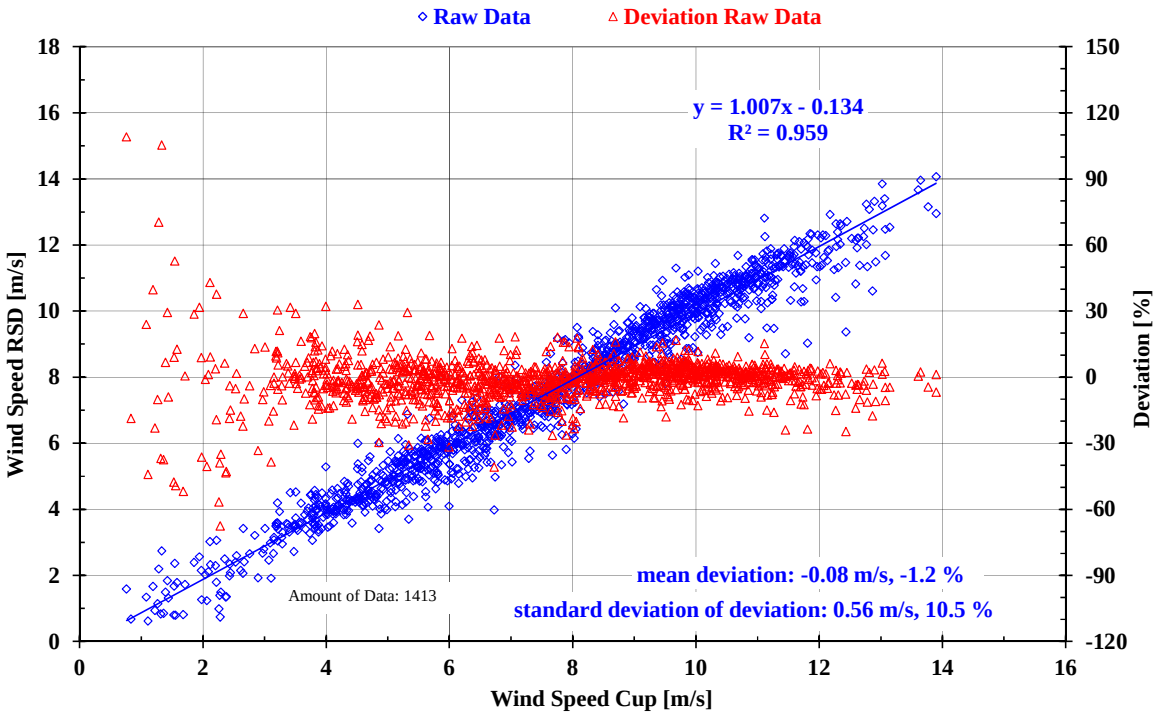

Figure 8.1 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 135 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.2 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 130 m Measurement Height

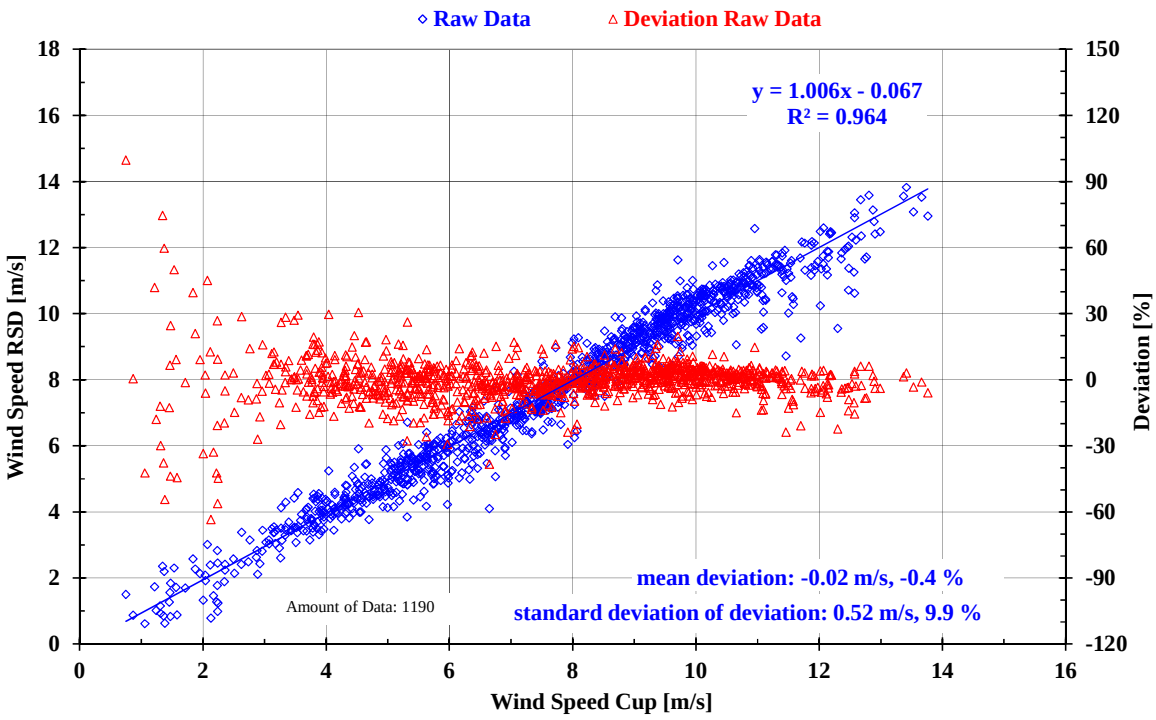

Figure 8.2 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 130 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.3 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 120 m Measurement Height

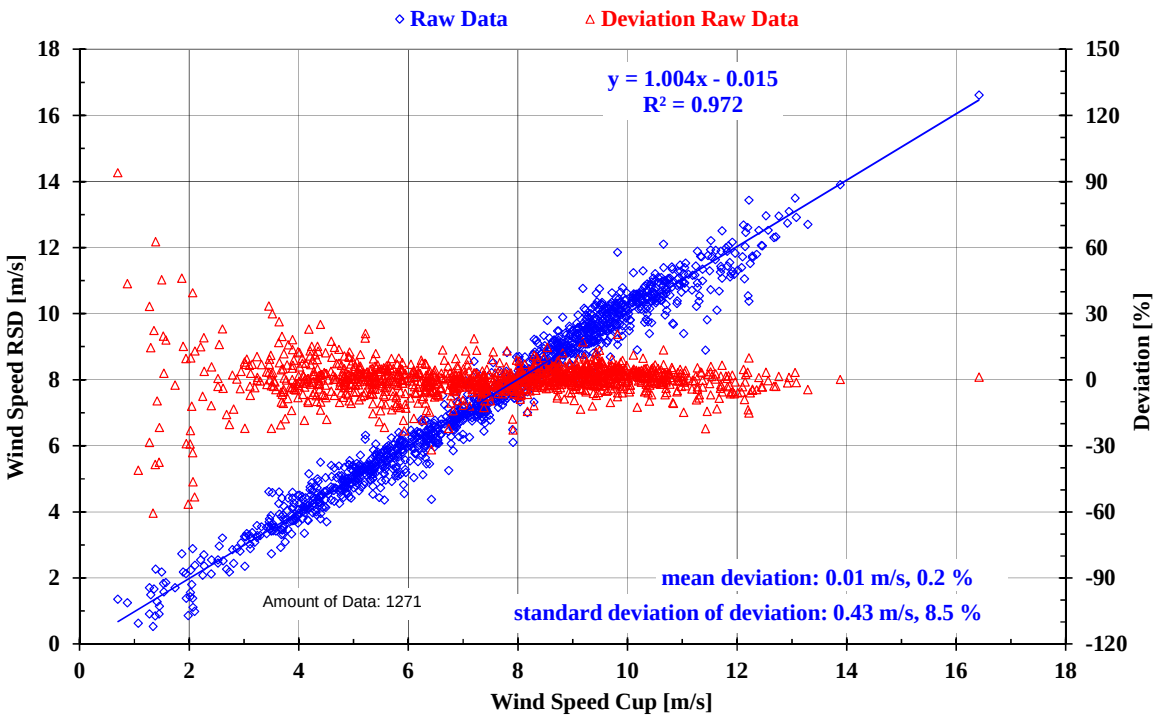

Figure 8.3 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 120 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.4 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 100 m Measurement Height

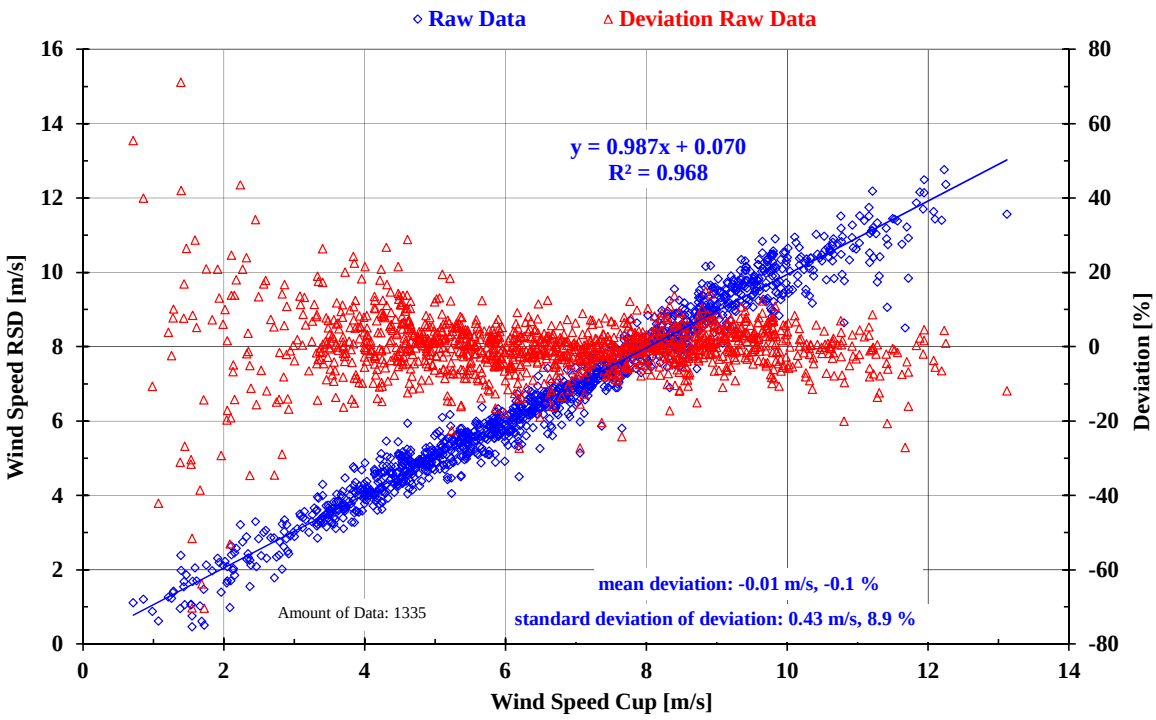

Figure 8.4 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 100 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.5 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 80 m Measurement Height

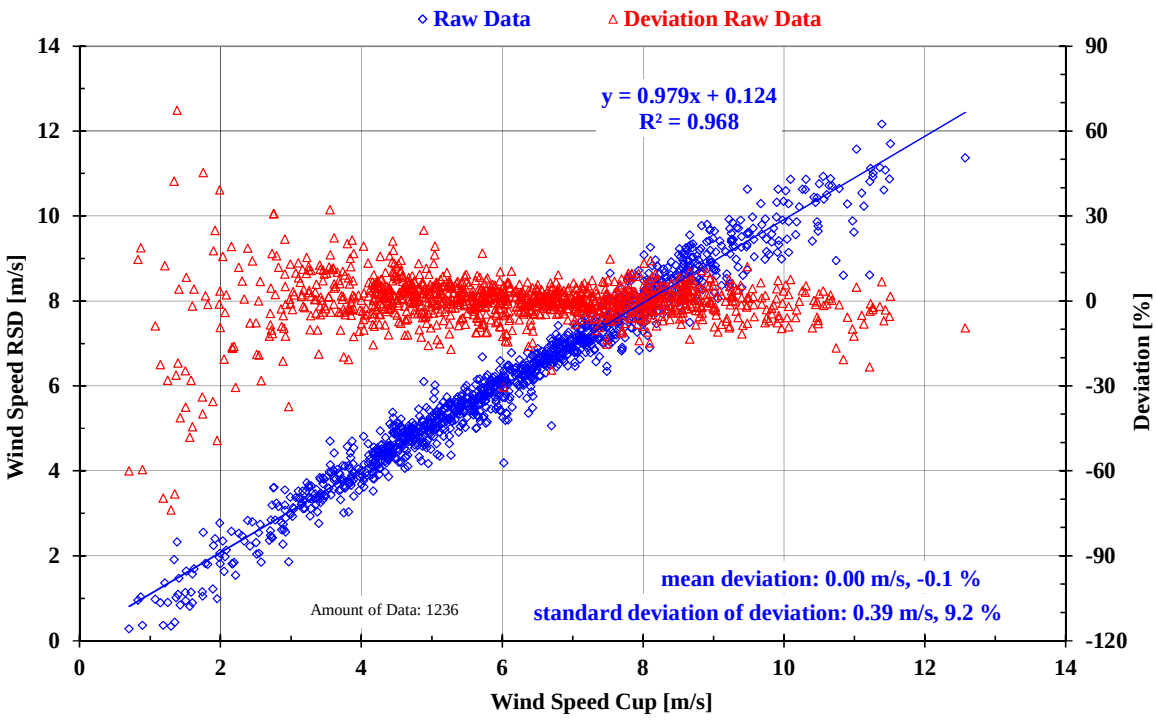

Figure 8.5 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 80 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.6 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 60 m Measurement Height

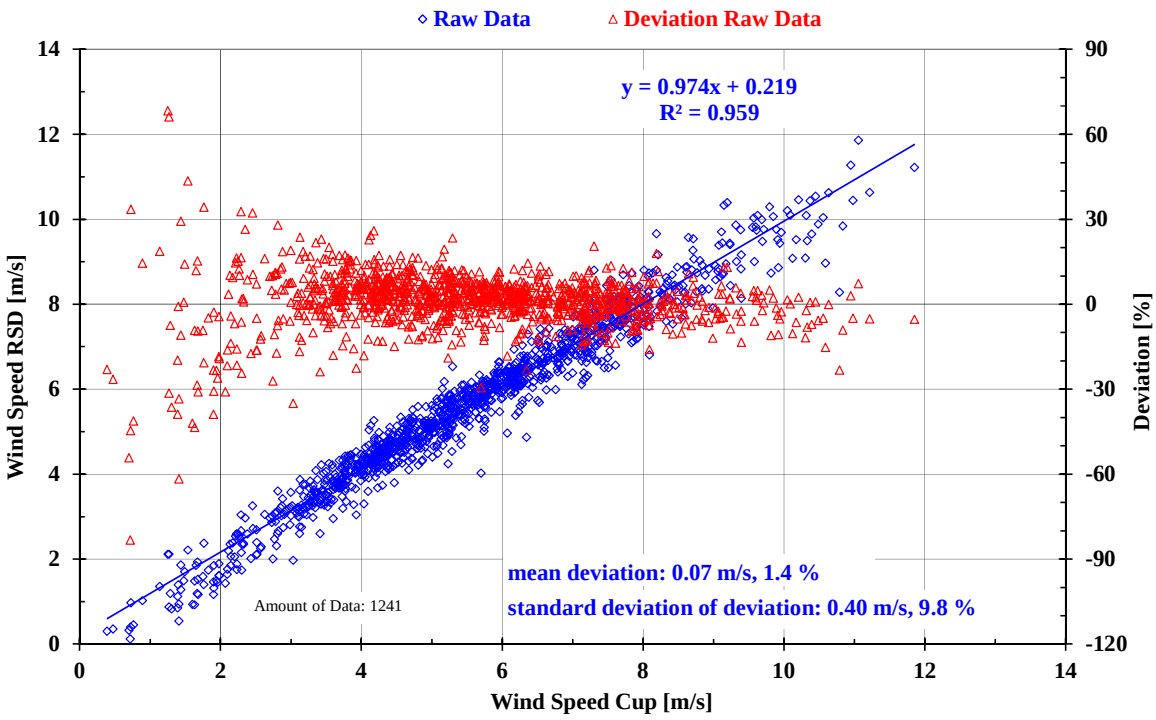

Figure 8.6 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 60 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

8.3.7 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 40 m Measurement Height

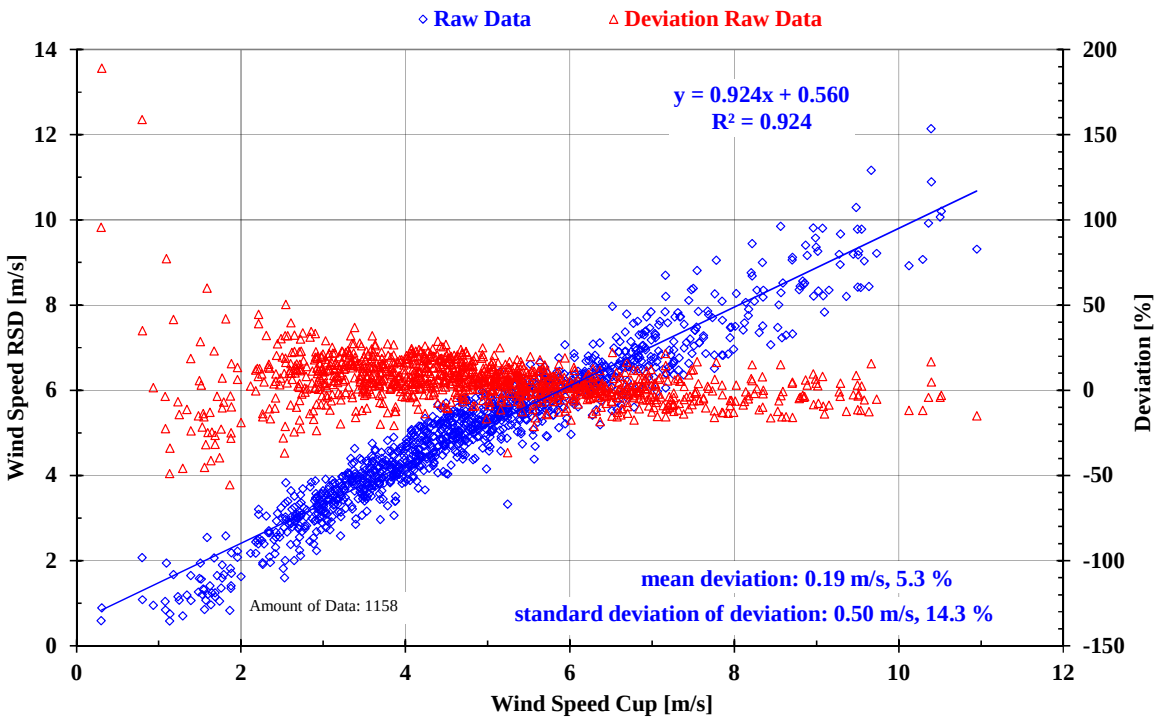

Figure 8.7 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 40 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.