



Calibration Report of Lidar Molas B300

Serial No.: 4

Site: Georgsfeld,(Germany)

Contracted by

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China

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Project No.: VC16418
Report No.: RSV17007.A1
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Revision History

Revision No.	Date	Status	Amendment
A0	2017-03-24	Final report	---
A1	2017-05-02	Final report	Offsets of wind vanes corrigated

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

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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 85 pages.

1 Introduction

The Molas B300 is a lidar system (lidar=light detection and ranging) for wind measurements in the lower atmosphere. This remote sensing device (RSD) has been developed by the Chinese company Movelaser with special intension to the needs of the wind energy industry. This report describes a test of the accuracy of a Molas B300 serial number 4 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 [1]. 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, detailed information of the mast [5]. Basis of this report is the calibration certificate RSV17005_Rev_1 [4].

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.

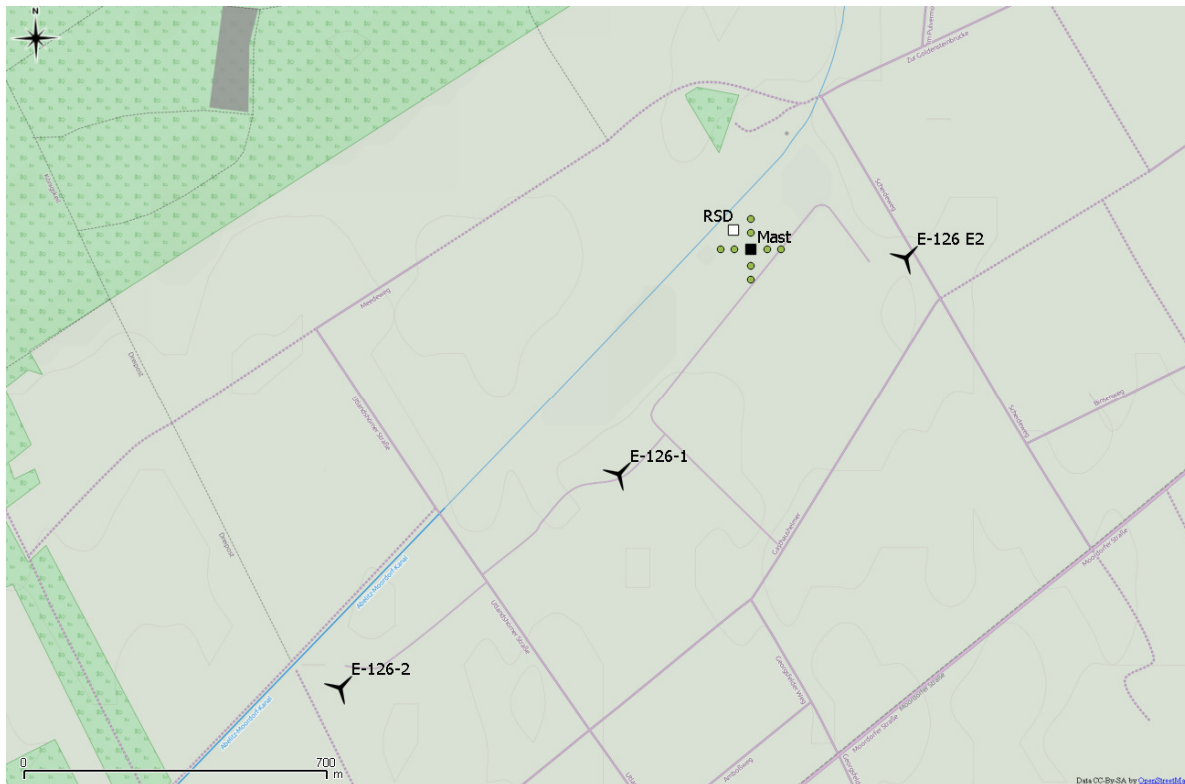


Figure 2.1: Map of the measurement site. The wind turbines E-126 limit the measurement sector. The met mast is marked by a black square with the black dots marking the anchor points of the guy wires. The RSD was located about 58 m northwest of the met mast. The maximum measurement sectors for the test are 242° to 58° and 133° to 178° . The maximum measurement sectors for the test are 242° to 58° and 133° to 177°

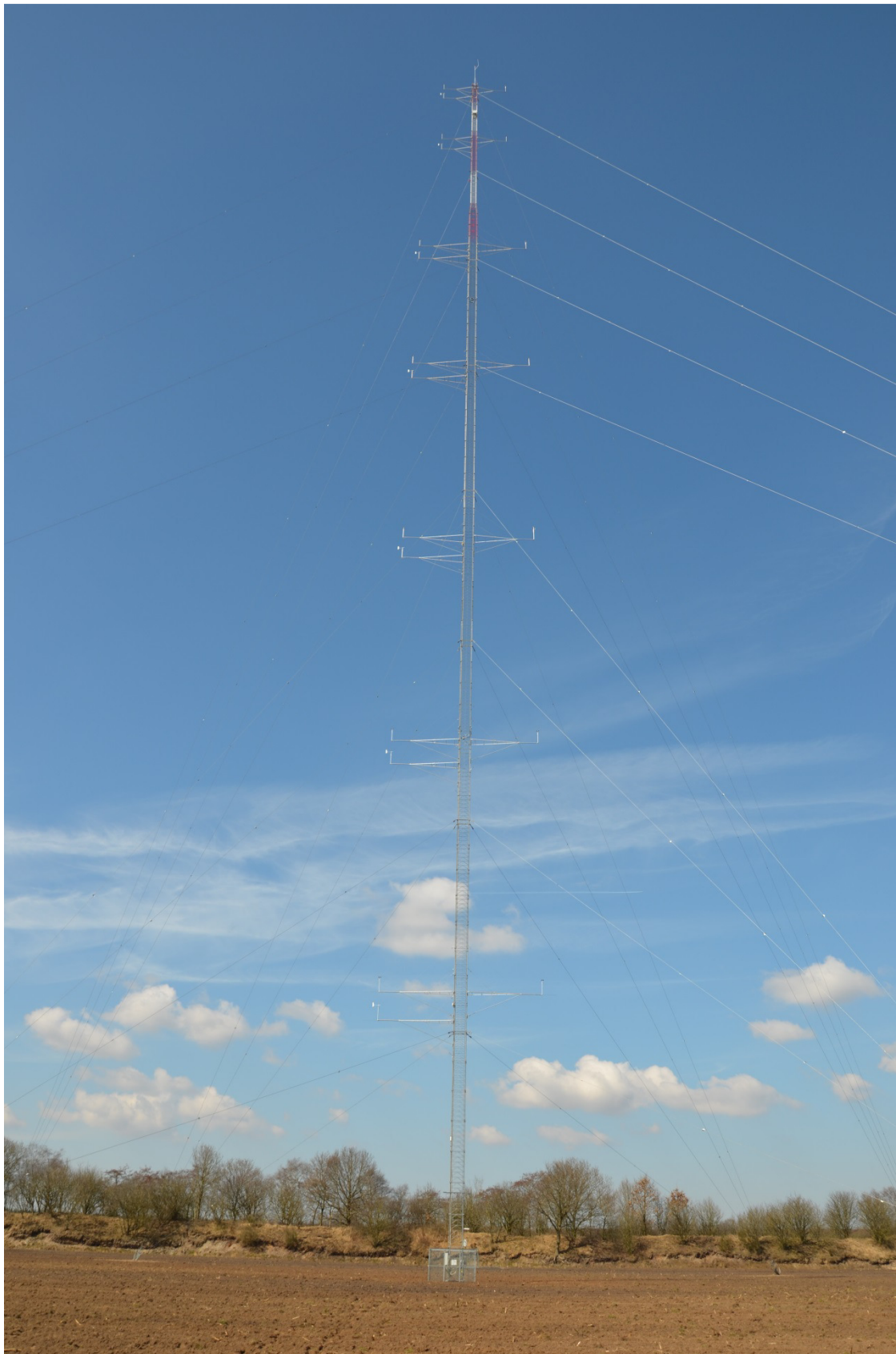


Figure 2.2: Photo of the 130 m high met mast near Georgsfeld, looking in direction southwest.

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 in a fenced area about 58 m next to 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 242° to 58° remains for testing the RSD. The measurement sector must be reduced further for some reference sensors due to mast effects (see Table 2.2).



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], [2]. The cup and also the ultrasonic anemometers have been calibrated in a wind tunnel according to DKD and MEASNET [3]. 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 lidar 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.

The RSD provides measurements only for heights above ground in integer multiples of meters, i.e. not exactly at the heights of the reference sensors of the mast. The measurements of the RSD have not been interpolated to the exact heights of the reference anemometers. The minimum measurement height of the RSD is limited to 40 m. For the comparison of the measurements of the RSD to the measurement of the cup anemometer the measurements of the met mast were interpolated to measurement height levels of the RSD by the application of a power law fitted to each individual 10-minute data set.

Object	Position		Rotor diameter D	Distance from met mast	Direction from met mast	Met Mast in Wake	
	X	Y				from	to
	[m]	[m]				[deg]	[deg]
Met mast	2595735	5931491	---	---	---	---	---
RSD	2595680	5929759	---	58	137	---	---
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 Selected Height	met mast sensor				RSD Complete sector		evaluation sector		
	signal	meas- urement height	boom ori- ent.	in mast wake		From	To	from	to
				from	to				
[m]	[-]	[m]	[°]	[°]	[°]	[°]	[°]	[°]	
134.75	V1	135.0 131.0	cen- tral	-	-	242 136	58 173	242 136	29 173
130.75	V2	131.0 120.4	225	29	54	242 136	58 161	242 136	29 174
120.75	V3	120.4 100.3	225	29	62	242 135	58 175	328 136 242	29 175 310
100.75	V5	100.3 82.2	225	30	62	242 135	58 175	242 135	30 175
81.75	V6	82.2 60.4	225	31	64	242 130	58 176	242 134	31 176
60.75	V8	60.4 40.3	225	31	64	242 129	58 177	242 133	31 177
40.75	V9	60.4 40.3	225	31	64	242 129	58 177	242 133	31 164
135.75	Dir1	129.0	225	29	54	242 136	58 173	242 136	29 173
120.75	Dir2	118.3	225	29	62	242 135	58 175	328 136 242	29 175 310
100.75	Dir3	98.2	225	30	62	242 135	58 175	242 135	30 175
81.75	Dir4	80.1	225	31	64	242 130	58 176	242 134	31 176
60.75	Dir5	58.2	225	31	64	242 129	58 177	242 133	31 177
40.75	Dir6	38.2	225	31	64	242 129	58 177	242 133	31 164

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.

Sensor	Height	Type	Serial	Calibration
Cup Anemometer v1	135.0 m	Thies First Class Adv.	03126287	1612271
Cup Anemometer v2	131.0 m	Thies First Class Adv.	03126295	1612275
Cup Anemometer v3	120.4 m	Thies First Class Adv.	03126277	1612269
Cup Anemometer v5	100.3 m	Thies First Class Adv.	03126289	1612276
Cup Anemometer v6	82.2 m	Thies First Class Adv.	03126301	1612273
Cup Anemometer v8	60.4 m	Thies First Class Adv.	03126298	1612277
Cup Anemometer v9	40.3 m	Thies First Class Adv.	03126275	1612272
Ultrasonic Anem. V13	131.0 m	Thies 2 D	02120013	1622319/20/21
Ultrasonic Anem. V14	100.4 m	Thies 2 D	02120014	1622313/14/15
Ultrasonic Anem. V15	60.5 m	Thies 2 D	02120015	1622316/17/18
Wind vane dir1	129.0 m	Thies First Class 4.3150.00.140	05120120	1622322
Wind vane dir2	118.3 m	Thies First Class 4.3150.00.140	05120122	1622310
Wind vane dir3	98.2 m	Thies First Class 4.3150.00.140	0809044	1622311
Wind vane dir4	80.1 m	Thies First Class 4.3150.00.140	0110052	1622306
Wind vane dir5	58.2 m	Thies First Class 4.3150.00.140	0209036	1622308
Wind vane dir6	38.2 m	Thies First Class 4.3150.00.140	0110051	1622309
Temperature T1/H1	130.6 m	Galtec + Mela KRC3/6.ME	94539	IK16_090
Temperature T4/H2	18.3 m	Galtec + Mela KRC3/6.ME	94541	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 2017-02-11 to 2017-03-15. The RSD was supplied by 230V/AC. 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	2017-02-11 to 2017-03-15
RSD model	Molas B300
Unit serial number	4
Beam angle from vertical	28°
Selected measurement heights	40.75 m, 60.75 m, 81.75 m, 100.75 m, 120.75 m, 130.75 m, 134.75 m
Height difference between RSD and Mast	0.75m
North orientation during test	337°
Power supply	230V
Firmware	2.1.1

Table 3.1 Basic information and key settings of the tested RSD

The vertical and horizontal alignment of the RSD was adjusted by staff of Movelas at the start of the measurements. The alignment was measured with a water spirit level. The horizontal orientation was controlled by a compass. The alignment did not change during the course of the measurements.

The data acquisition system of the met mast has been synchronised to CET, the RSD has been synchronised to CET+7. During the measurement period, the time was synchronised by internet via GSM connection.

3.2 Data Collection

The RSD stores the data files containing statistics of 10-minute periods by an internal computer. The measurement data of the RSD was sent by email.

3.3 Data Processing

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

The RSD allows measurement height selection only in integer meter values. 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. 100.3 m and 82.2 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:

- 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 [3]. 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.
- Only 10-minute periods, where the availability signal of the RSD is >80 have been considered.

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 filter on the availability signal of the RSD is applied.

3.5 Measurement uncertainties

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. According to IEC 61400-12-1, ed. 2, [1] the uncertainty components as listed in Figure 3.1 have been considered in order to evaluate the uncertainty of the measurements of the RSD.

The uncertainties are considered to be independent from each other. Thus the combined uncertainty is the square root of the summed squares of the uncertainty components. The components of the uncertainties are explained in the following subchapters.

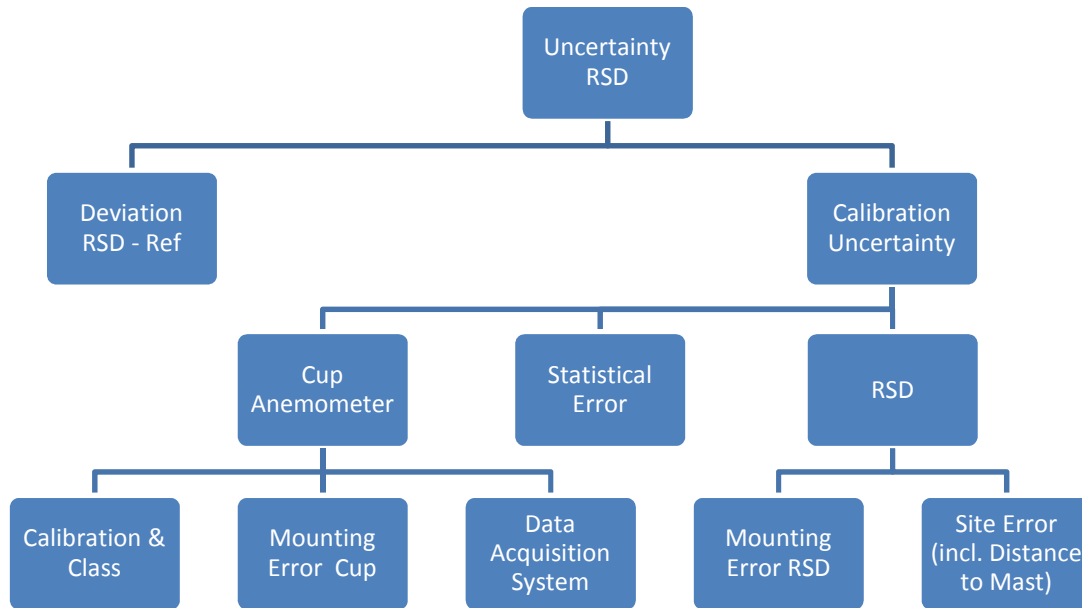


Figure 3.1 Illustration of uncertainty components of final RSD uncertainty.

3.5.1 Measurement uncertainties of the reference anemometer

(a) Calibration of the reference anemometer

The uncertainty of the calibration of the reference is:

$$U_{calibration} = u_{cal}/U_i$$

With $u_{cal} = 0.025 \text{ m/s}$ and U_i as averaged wind speed for respective wind speed class

(b) Classification of the reference anemometer

The sensitivity of the reference is considered according [1], Annex I by an anemometer classification. For the standard uncertainty of the classification is obtained with:

$$u_{class} = kl * (0.05 \text{ m/s} + 0.005 U_i) / \sqrt{3}$$

U_i is the average wind speed of the respective class of wind speed i , and kl is the anemometer class ($kl=0.9$ for Thies First Class Advanced)

(c) Vertical alignment of reference anemometer

The vertical mounting accuracy of the anemometers is assumed with $\pm 1^\circ$.

$$u_{vert,A} = (1 - \cos(1^\circ / \sqrt{3})) U_i$$

(d) Vertical alignment of reference mast

The vertical alignment of the mast is assumed with $\pm 1^\circ$.

$$u_{vert,A} = (1 - \cos(1^\circ / \sqrt{3})) U_i$$

(e) Mast effects top mounted anemometer

The standard uncertainty of the mast effects to the top mounted anemometer are derived from the 1:11 rule, i.e. is a cone adhered of 1:11 an uncertainty of 0.5% will be as-

sumed. For other cosine relations it is assumed that the uncertainty is inversely proportional to the cosine relation. For the met mast in Georgsfeld the uncertainty is:

$$u_{top}=424 \text{ mm}/4670 \text{ mm} * 11 * 0.005 * U_i = 0.0050 * U_i.$$

(f) Mast effects boom mounted anemometer

The flow effects of the mast to the reference anemometer are corrected by internal tools.

(g) Horizontal booms

The acceleration effects of the horizontal boom influences the measurement of the anemometer with 0.5% in a distance of 20 times [1]. For higher distances it is assumed that the influence is inversely proportional to the distance. For a vertical distance of 1000 mm over the horizontal boom with a diameter of 48 mm the following uncertainty results:

$$u_{horAusl}=0.0048 * U_i.$$

(h) Data acquisition system

The Campbell CR1000 has an accuracy of 1 Hz per sample by a range of 1500 Hz. For a Thies First Class Advanced this range corresponds to 75 m/s. For the cup anemometer this results to the data acquisition system to a failure of

$$u_{DAS}=75 \text{ m/s} / 1500 \text{ Hz} * 1 \text{ Hz} / \sqrt{(3*600)}=0.0012 \text{ m/s}.$$

3.5.2 Statistical Error

The statistical uncertainty of comparison between RSD and reference sensor is determined from the statistical uncertainty of the class average of difference between reference and RSD.

$$u_{stat}=\sigma(\Delta v)/\sqrt{n}$$

3.5.3 Measurement uncertainties of RSD

(a) Vertical alignment of reference anemometer

For remote sensing devices it is assumed that they act cosine-like to marginal tilt. For installation of a RSD device it's generally assumed that an accuracy of 1° is reached.

Thus the uncertainty results to:

$$u_{vert,p}=(1-\cos(1^\circ/\sqrt{3})) * U_i$$

(b) Measurement resolution

The data recording of remote sensing devices is saved as ASCII-format. The uncertainties of the resolution of the RSD for a 10-min sample is given by

$$u_{DAS,p}=10^{-n}/(2\sqrt{3}) \text{ m/s}$$

Whereby n is the amount of decimal places of the saved data.

(c) Site effect errors

Due to the spatial separation of the measured volumes of the reference to the RSD, errors arise which are determined by the location. Analog to [1] it is assumed that the failure increases linear with increasing the distance between midpoint of probe volume of the RSD. Thus it results:

$$u_{site}=0.01*d/h*U_i$$

where by h is the measurement height over the ground and d is the horizontal distance between the midpoint of probe volume and the reference.

4 Results of Calibration Test

4.1.1 Availability of the RSD

A total amount of 4719 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 lidar operated without malfunction.

As can be seen in Figure 4.1, the availability of horizontal wind speed has very high values of more than 99% for measurement heights between 40 m and 140 m. Above measurement height of 100m the availability begins slightly to decrease.

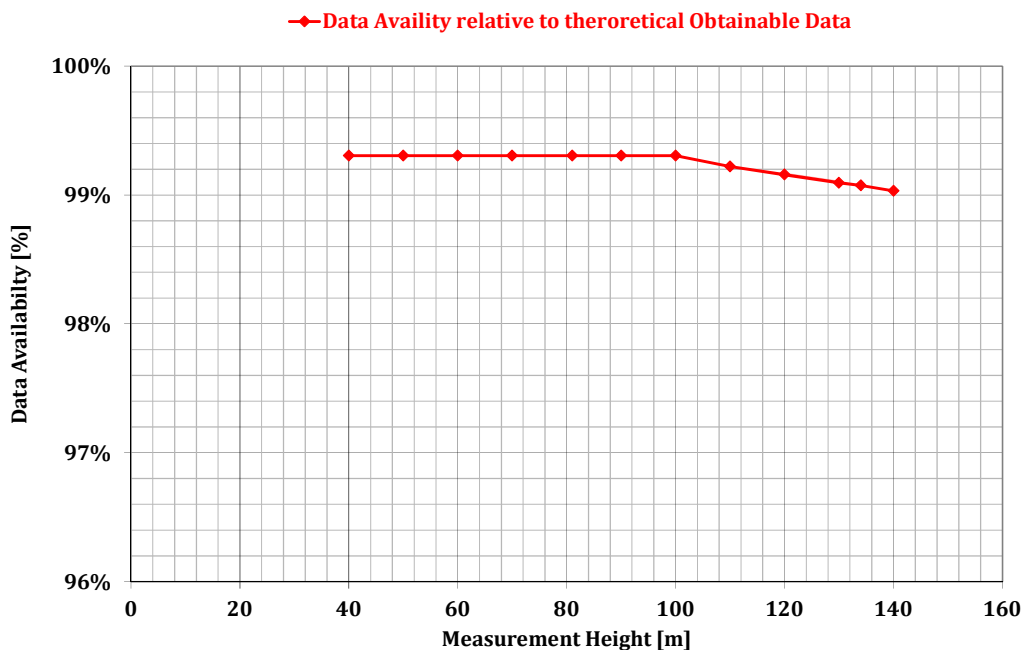


Figure 4.1: Availability of measurement of the horizontal wind speed component at different heights as measured by RSD.

4.2 Accuracy of the RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed

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 135 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 an excellent correlation (square of correlation coefficient more than 0.99 0.97).
- For measurements height between 135 m and 60 m the horizontal wind speed component of the RSD is marginal underestimated with about -0.1% to - 0.4% or -0.03 m/s to -0.04 m/s.

- For measurements height between 135 m and 40 m the horizontal wind speed component of the RSD show values of standard deviation of deviation of about slightly above 1.9% - 3.4%.
- The scatter plots of horizontal wind speed components show an excellent accuracy with a very good precision.
- The lowest measurement height of 40m is in average underestimated with -2% (Figure 4.15). This deviation could be a result of the lengths of the RSDs probe volumes which may be affected of wake effects of surrounding trees.

As the statistics gained from the 10-minute raw 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 135m to 60m the bin averaged deviation of the RSD is smaller than the uncertainty of the reference anemometer for most bins (Figure 4.6, Figure 4.8, Figure 4.10, 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%.

The resulting wind speed dependent uncertainties of the measurements of the horizontal wind speed component by the RSD are in the order of about 2% (expanded uncertainty $k=2$) in most wind speed bins for all measurement heights. The variation of the uncertainty reaches from 1.7% to 8.2% (expanded uncertainty $k=2$) 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.

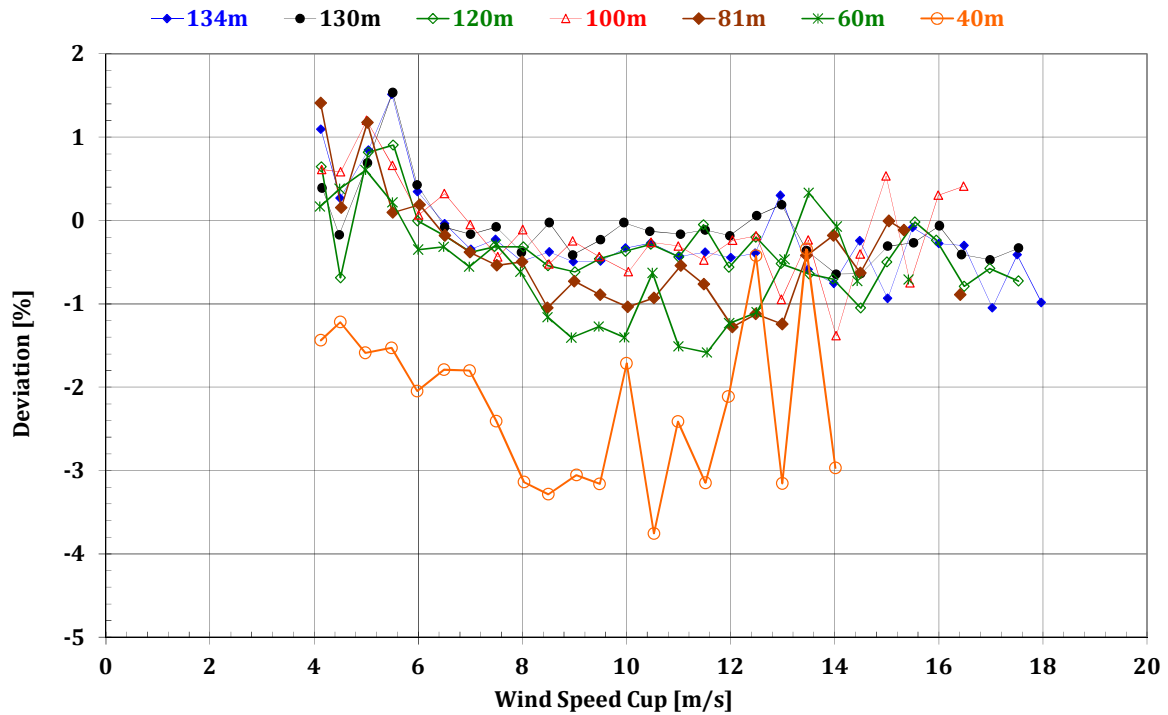


Figure 4.2 Overview of bin averaged deviations of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at several heights. A positive sign of the shown deviation represents higher values measured by RSD.

4.2.1 Accuracy of RSD in Terms of 10-Minute Averages of the Horizontal Wind Speed Component at 134.75 m Measurement Height

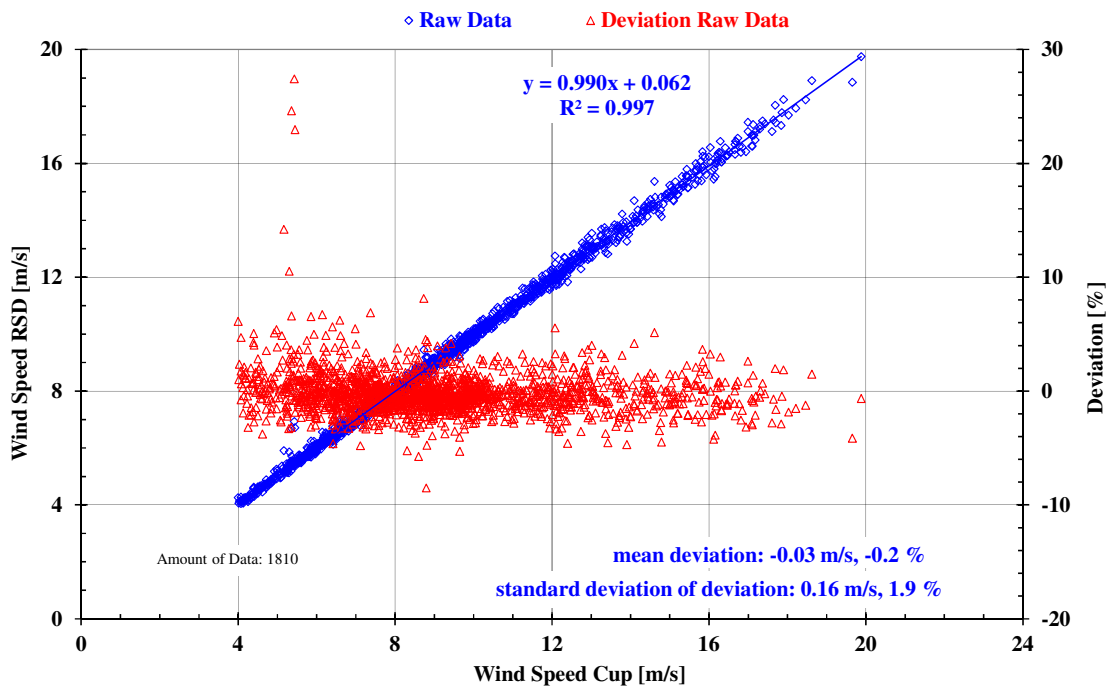


Figure 4.3 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 134.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

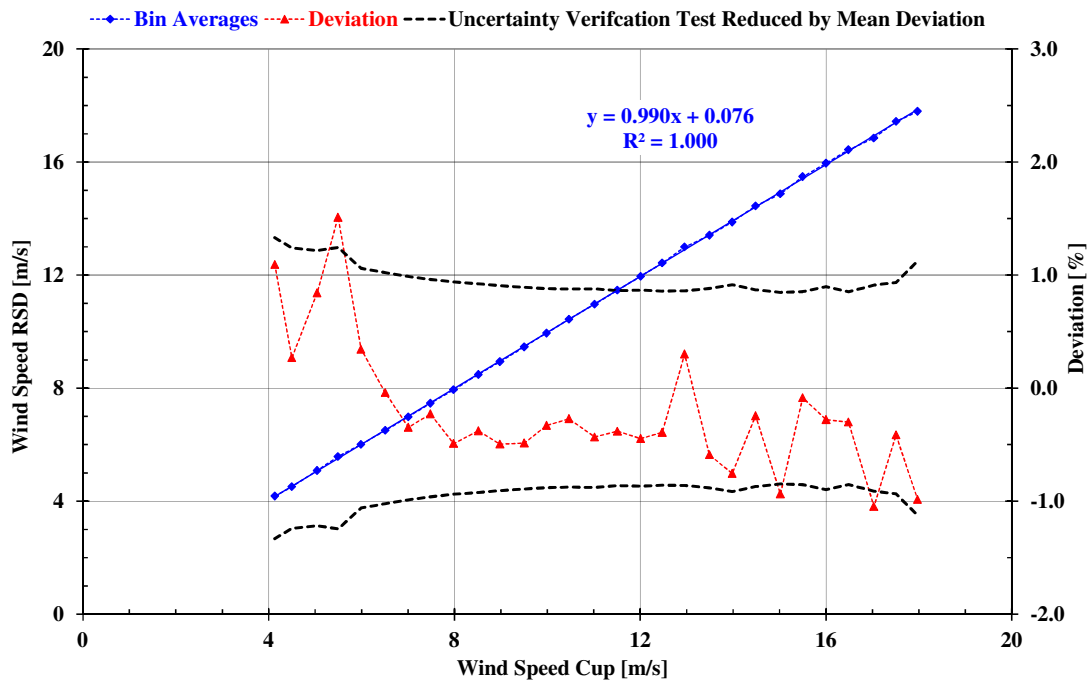


Figure 4.4: Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 134.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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 (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]
4.131	4.176	19	4.267	4.047	0.074	0.017	0.045	2.66	0.110	3.45	0.142
4.499	4.511	43	4.885	4.118	0.164	0.025	0.012	2.48	0.112	2.54	0.114
5.042	5.084	42	5.902	4.741	0.228	0.035	0.043	2.43	0.123	2.96	0.149
5.494	5.577	73	6.925	5.121	0.300	0.035	0.083	2.49	0.137	3.92	0.215
5.989	6.009	98	6.559	5.673	0.191	0.019	0.021	2.12	0.127	2.23	0.133
6.510	6.508	100	7.004	6.122	0.185	0.018	-0.003	2.05	0.133	2.05	0.133
7.008	6.984	118	7.367	6.592	0.185	0.017	-0.024	1.97	0.138	2.09	0.147
7.483	7.466	138	7.929	7.016	0.170	0.015	-0.017	1.92	0.144	1.98	0.148
7.983	7.944	119	8.366	7.560	0.166	0.015	-0.039	1.88	0.150	2.12	0.169
8.516	8.484	143	9.444	7.875	0.202	0.017	-0.032	1.85	0.157	2.00	0.170
8.979	8.934	167	9.474	8.048	0.186	0.014	-0.045	1.81	0.163	2.07	0.186
9.505	9.459	141	9.939	8.923	0.186	0.016	-0.046	1.78	0.170	2.03	0.193
9.982	9.949	114	10.476	9.441	0.194	0.018	-0.033	1.76	0.176	1.88	0.188
10.465	10.436	60	10.939	10.130	0.191	0.025	-0.028	1.75	0.183	1.83	0.192
11.019	10.972	44	11.613	10.511	0.213	0.032	-0.048	1.76	0.194	1.96	0.216
11.510	11.466	51	12.039	11.078	0.206	0.029	-0.044	1.73	0.199	1.89	0.217
12.008	11.954	54	12.746	11.551	0.227	0.031	-0.054	1.73	0.208	1.95	0.234
12.474	12.425	48	12.830	11.831	0.242	0.035	-0.049	1.72	0.214	1.89	0.235
12.955	12.994	41	13.537	12.611	0.236	0.037	0.039	1.72	0.223	1.82	0.236
13.490	13.410	31	13.852	12.816	0.282	0.051	-0.080	1.76	0.238	2.12	0.286
13.981	13.876	22	14.686	13.254	0.320	0.068	-0.106	1.83	0.256	2.37	0.332
14.484	14.449	25	15.363	13.960	0.269	0.054	-0.035	1.74	0.252	1.81	0.262
15.017	14.876	25	15.352	14.124	0.262	0.052	-0.141	1.69	0.254	2.52	0.379
15.497	15.484	21	15.996	15.077	0.264	0.058	-0.013	1.71	0.265	1.72	0.266
16.002	15.958	24	16.554	15.381	0.314	0.064	-0.045	1.80	0.288	1.88	0.301
16.484	16.434	17	16.880	16.041	0.262	0.063	-0.050	1.70	0.281	1.81	0.298
17.031	16.852	14	17.437	16.385	0.337	0.090	-0.178	1.82	0.310	2.78	0.473
17.507	17.435	8	18.038	17.116	0.280	0.099	-0.072	1.87	0.327	2.04	0.358
17.971	17.794	5	18.240	17.325	0.335	0.150	-0.177	2.25	0.404	2.99	0.537

Table 4.1 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 134.75 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 130.75 m Measurement Height

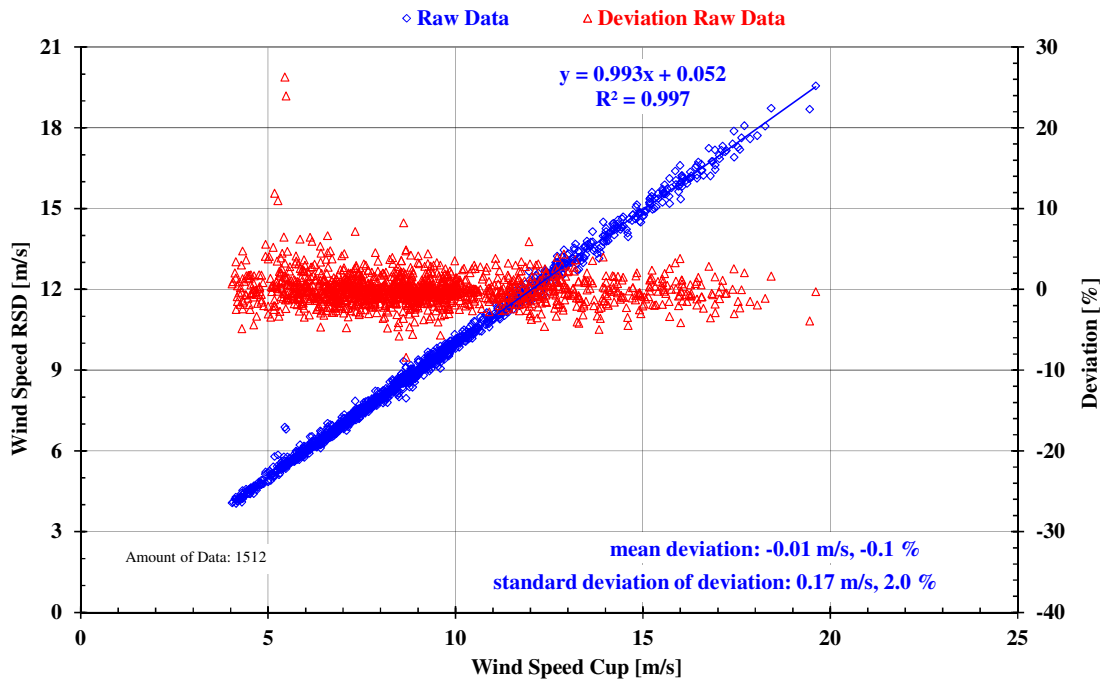


Figure 4.5 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 130.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

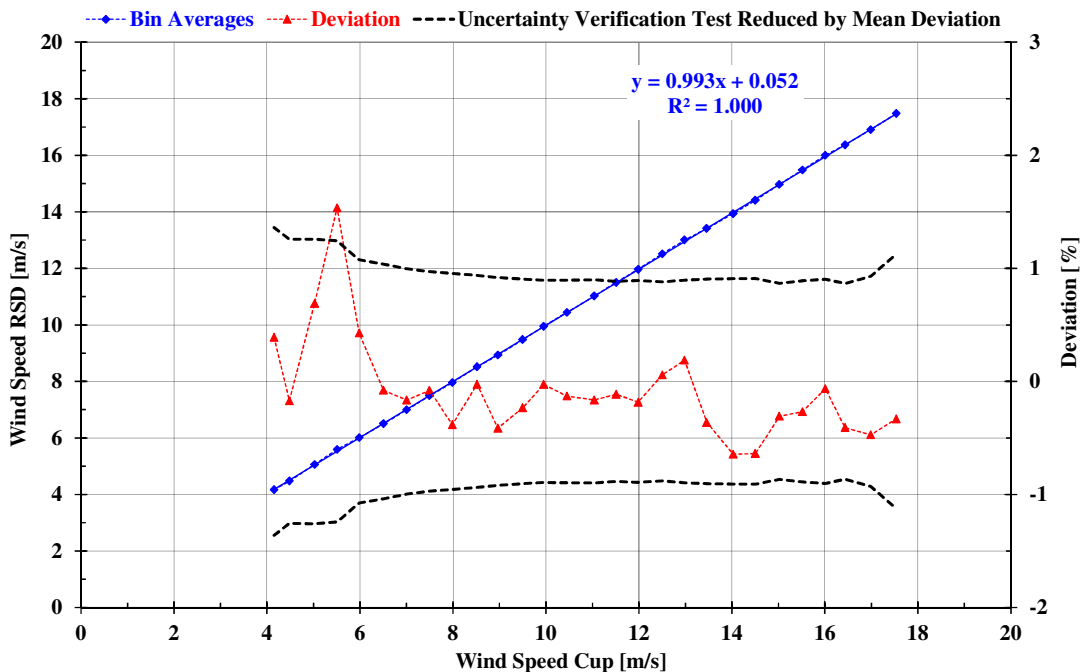


Figure 4.6 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.151	4.168	11	4.283	4.043	0.078	0.024	0.016	2.722	0.113	2.831	0.118
4.483	4.475	37	4.706	4.094	0.155	0.026	-0.008	2.512	0.113	2.535	0.114
5.025	5.060	34	5.792	4.744	0.234	0.040	0.035	2.518	0.127	2.871	0.144
5.508	5.593	64	6.882	5.116	0.286	0.036	0.085	2.486	0.137	3.950	0.218
5.982	6.007	76	6.538	5.667	0.190	0.022	0.026	2.151	0.129	2.314	0.138
6.508	6.502	86	7.025	6.103	0.197	0.021	-0.005	2.076	0.135	2.082	0.136
7.007	6.995	113	7.380	6.607	0.196	0.018	-0.012	1.992	0.140	2.019	0.142
7.497	7.491	123	7.861	7.142	0.169	0.015	-0.006	1.943	0.146	1.949	0.146
7.986	7.955	90	8.319	7.616	0.166	0.018	-0.031	1.910	0.153	2.058	0.164
8.519	8.517	135	9.329	7.954	0.215	0.019	-0.002	1.875	0.160	1.876	0.160
8.968	8.931	125	9.444	8.365	0.212	0.019	-0.037	1.839	0.165	2.016	0.181
9.501	9.479	128	9.980	8.970	0.195	0.017	-0.022	1.809	0.172	1.868	0.177
9.953	9.950	79	10.495	9.526	0.192	0.022	-0.003	1.789	0.178	1.790	0.178
10.452	10.438	45	10.964	10.061	0.216	0.032	-0.014	1.792	0.187	1.811	0.189
11.041	11.023	36	11.497	10.600	0.206	0.034	-0.018	1.797	0.198	1.827	0.202
11.513	11.500	40	11.971	11.022	0.215	0.034	-0.013	1.770	0.204	1.785	0.205
11.984	11.962	49	12.667	11.563	0.271	0.039	-0.022	1.785	0.214	1.823	0.218
12.503	12.511	43	13.222	11.804	0.293	0.045	0.007	1.760	0.220	1.764	0.221
12.979	13.004	33	13.685	12.509	0.285	0.050	0.024	1.792	0.233	1.831	0.238
13.459	13.410	24	14.142	12.738	0.314	0.064	-0.049	1.810	0.244	1.950	0.262
14.028	13.937	25	14.500	13.149	0.362	0.072	-0.090	1.816	0.255	2.227	0.312
14.505	14.412	17	14.773	13.953	0.238	0.058	-0.093	1.819	0.264	2.223	0.322
15.020	14.973	23	15.603	14.494	0.304	0.063	-0.046	1.734	0.260	1.841	0.276
15.517	15.476	18	16.117	14.970	0.305	0.072	-0.042	1.780	0.276	1.859	0.288
16.009	15.999	19	16.602	15.350	0.278	0.064	-0.010	1.807	0.289	1.811	0.290
16.434	16.367	13	16.723	16.125	0.206	0.057	-0.067	1.730	0.284	1.913	0.314
16.985	16.905	13	17.320	16.209	0.337	0.093	-0.080	1.860	0.316	2.085	0.354
17.535	17.477	7	18.075	16.906	0.407	0.154	-0.058	2.249	0.394	2.345	0.411

Table 4.2 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 130.75 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 120.75 m Measurement Height

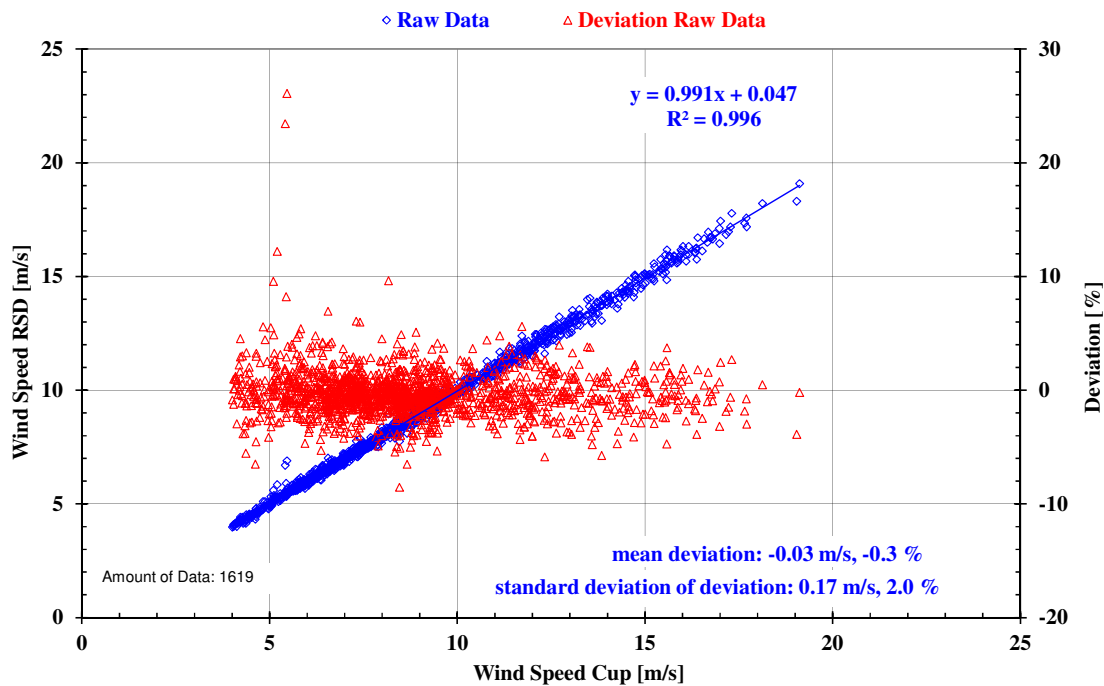


Figure 4.7 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 120.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

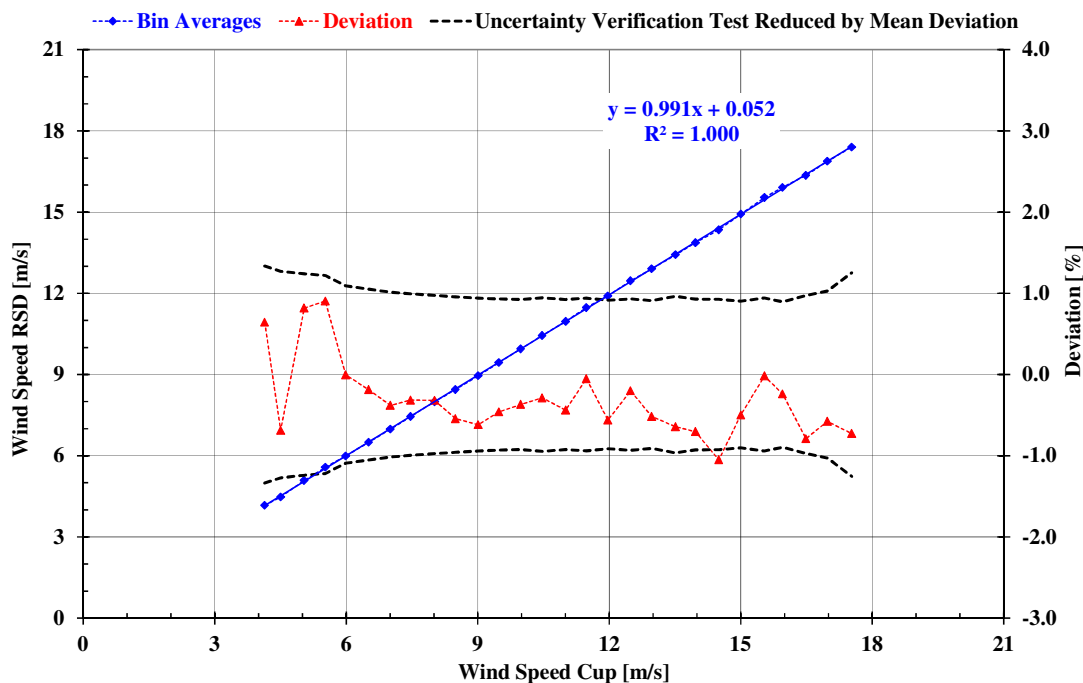


Figure 4.8 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.140	4.167	19	4.415	3.978	0.122	0.028	0.027	2.67	0.111	2.97	0.123
4.505	4.474	44	4.865	4.129	0.177	0.027	-0.031	2.54	0.115	2.89	0.130
5.042	5.083	48	5.843	4.700	0.228	0.033	0.041	2.48	0.125	2.97	0.150
5.523	5.573	74	6.891	5.138	0.269	0.031	0.050	2.44	0.135	3.04	0.168
5.988	5.988	81	6.520	5.666	0.176	0.020	0.000	2.19	0.131	2.19	0.131
6.510	6.498	114	7.011	6.035	0.189	0.018	-0.012	2.10	0.137	2.14	0.139
7.008	6.981	136	7.445	6.514	0.191	0.016	-0.027	2.03	0.142	2.17	0.152
7.470	7.446	137	7.917	7.057	0.160	0.014	-0.023	1.99	0.149	2.08	0.156
8.019	7.994	118	8.958	7.506	0.206	0.019	-0.025	1.95	0.156	2.05	0.165
8.492	8.446	160	8.980	7.741	0.199	0.016	-0.046	1.92	0.163	2.20	0.187
9.010	8.955	134	9.447	8.315	0.210	0.018	-0.056	1.88	0.170	2.25	0.203
9.483	9.439	122	9.997	8.948	0.228	0.021	-0.044	1.86	0.176	2.08	0.197
9.983	9.947	50	10.451	9.566	0.195	0.028	-0.037	1.85	0.184	1.99	0.199
10.470	10.440	31	10.792	10.064	0.194	0.035	-0.030	1.89	0.198	1.98	0.207
11.007	10.959	48	11.666	10.517	0.238	0.034	-0.048	1.85	0.204	2.05	0.225
11.479	11.474	40	12.382	11.116	0.281	0.044	-0.006	1.88	0.216	1.88	0.216
11.970	11.903	46	12.508	11.402	0.293	0.043	-0.067	1.83	0.219	2.15	0.257
12.488	12.463	37	13.220	11.608	0.318	0.052	-0.025	1.86	0.233	1.91	0.238
12.971	12.904	31	13.502	12.402	0.274	0.049	-0.067	1.82	0.236	2.09	0.272
13.511	13.425	24	14.046	12.839	0.322	0.066	-0.087	1.93	0.261	2.32	0.313
13.968	13.869	20	14.287	13.053	0.291	0.065	-0.098	1.86	0.259	2.33	0.325
14.501	14.348	23	15.063	13.594	0.336	0.070	-0.152	1.85	0.269	2.80	0.406
15.003	14.928	20	15.565	14.470	0.249	0.056	-0.075	1.81	0.271	2.06	0.310
15.541	15.538	20	16.167	14.843	0.330	0.074	-0.003	1.88	0.293	1.89	0.293
15.954	15.916	15	16.322	15.579	0.235	0.061	-0.038	1.79	0.286	1.86	0.296
16.489	16.359	11	16.951	15.743	0.369	0.111	-0.130	1.94	0.321	2.51	0.413
16.978	16.881	8	17.431	16.447	0.300	0.106	-0.098	2.06	0.349	2.36	0.400
17.532	17.405	5	17.775	17.169	0.262	0.117	-0.127	2.51	0.439	2.90	0.508

Table 4.3 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 120.75 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 100.75 m Measurement Height

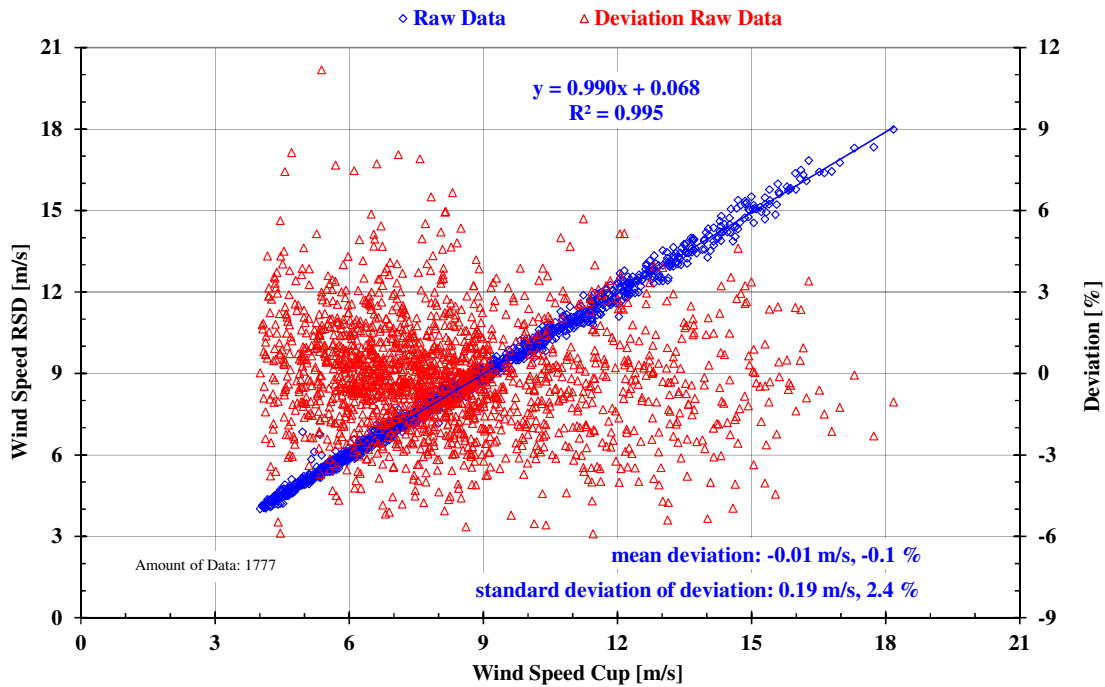


Figure 4.9 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 100.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

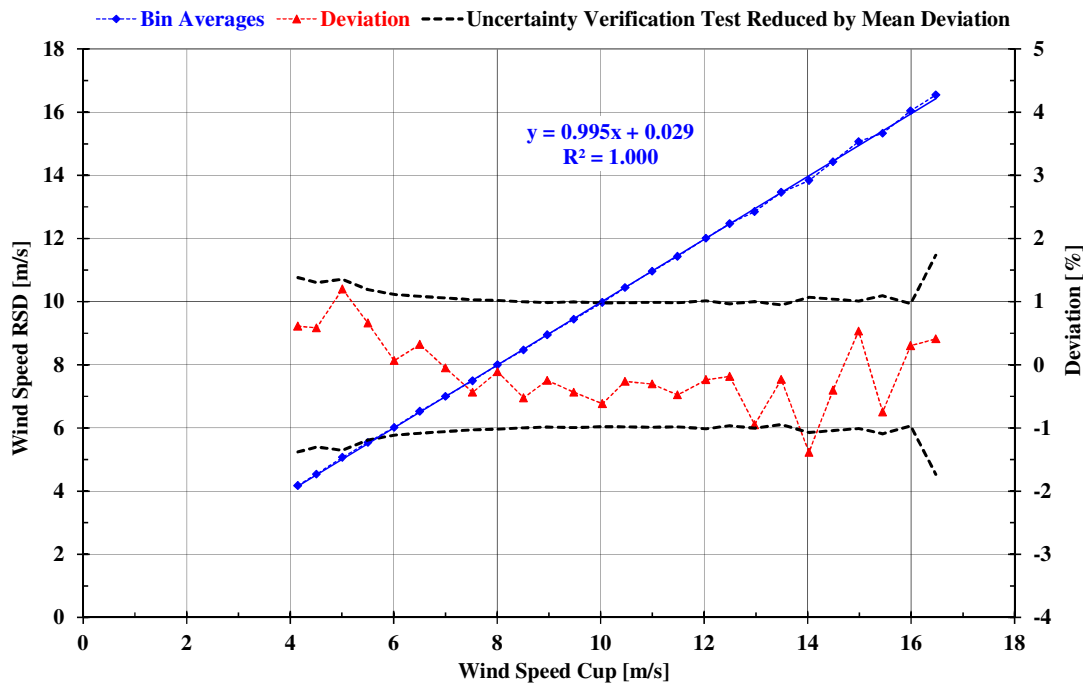


Figure 4.10 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 100.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.148	4.174	23	4.356	4.012	0.106	0.022	0.025	2.76	0.115	3.02	0.125
4.510	4.536	68	5.098	4.148	0.190	0.023	0.026	2.60	0.117	2.85	0.129
5.009	5.069	71	6.844	4.645	0.306	0.036	0.060	2.71	0.136	3.62	0.181
5.504	5.540	106	6.746	5.166	0.224	0.022	0.036	2.38	0.131	2.72	0.150
6.010	6.014	142	6.570	5.500	0.176	0.015	0.004	2.23	0.134	2.23	0.134
6.505	6.526	159	7.130	5.999	0.197	0.016	0.021	2.17	0.141	2.26	0.147
7.002	6.999	154	7.677	6.428	0.218	0.018	-0.003	2.12	0.148	2.12	0.148
7.527	7.494	162	8.186	7.016	0.198	0.016	-0.033	2.06	0.155	2.24	0.169
8.007	7.998	155	8.651	7.162	0.237	0.019	-0.009	2.04	0.163	2.05	0.164
8.511	8.467	156	8.956	7.886	0.211	0.017	-0.045	1.99	0.170	2.25	0.192
8.969	8.947	117	9.530	8.473	0.206	0.019	-0.022	1.97	0.177	2.03	0.182
9.480	9.439	47	9.946	9.019	0.238	0.035	-0.041	1.99	0.188	2.17	0.206
10.035	9.973	60	10.600	9.483	0.252	0.032	-0.062	1.96	0.197	2.32	0.232
10.473	10.445	51	11.272	9.825	0.269	0.038	-0.027	1.96	0.206	2.03	0.213
10.997	10.963	43	11.880	10.383	0.273	0.042	-0.034	1.98	0.217	2.07	0.227
11.487	11.432	49	12.129	10.783	0.342	0.049	-0.055	1.97	0.226	2.19	0.251
12.038	12.009	39	12.785	11.091	0.372	0.060	-0.029	2.03	0.244	2.08	0.250
12.495	12.472	30	13.153	11.923	0.323	0.059	-0.023	1.93	0.241	1.97	0.246
12.975	12.852	30	13.524	12.317	0.325	0.059	-0.123	2.00	0.260	2.76	0.358
13.491	13.460	33	13.985	12.946	0.302	0.053	-0.031	1.89	0.256	1.95	0.263
14.027	13.833	14	14.362	13.267	0.336	0.090	-0.194	2.14	0.300	3.50	0.491
14.491	14.432	22	15.378	13.864	0.390	0.083	-0.058	2.08	0.302	2.23	0.324
14.986	15.066	16	15.503	14.541	0.243	0.061	0.080	2.02	0.303	2.28	0.342
15.449	15.333	12	15.975	14.682	0.390	0.112	-0.116	2.19	0.338	2.65	0.410
15.991	16.040	10	16.484	15.731	0.281	0.089	0.048	1.94	0.310	2.03	0.325
16.478	16.545	3	16.837	16.381	0.253	0.146	0.068	3.47	0.572	3.57	0.587

Table 4.4 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 100.75 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 81.75 m Measurement Height

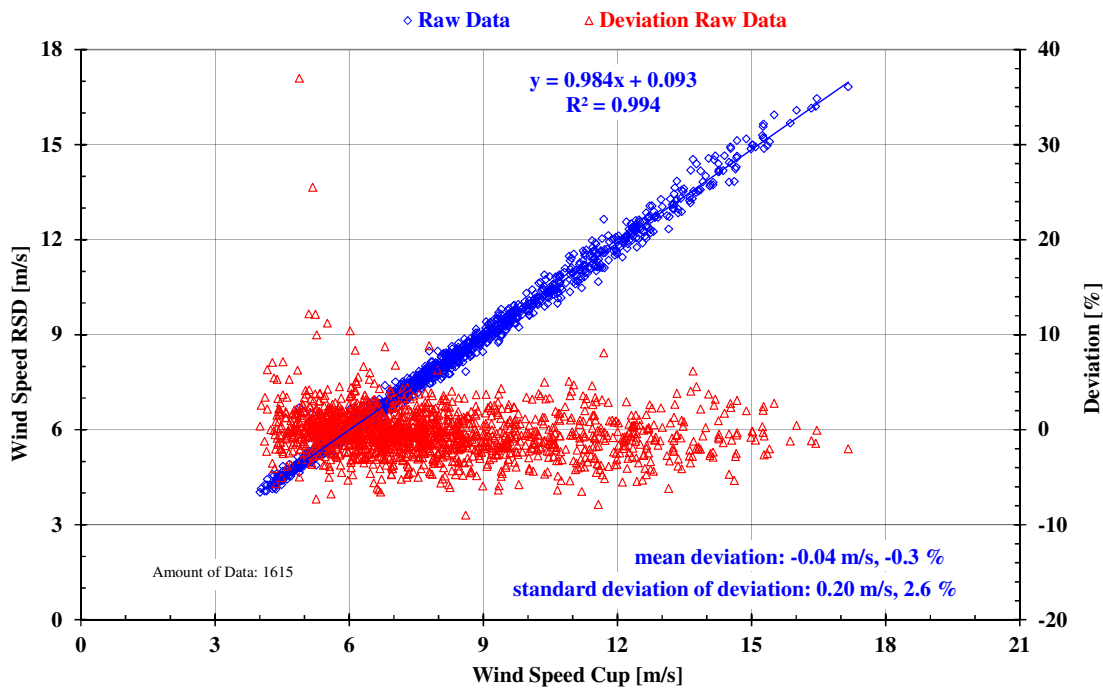


Figure 4.11 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 81.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

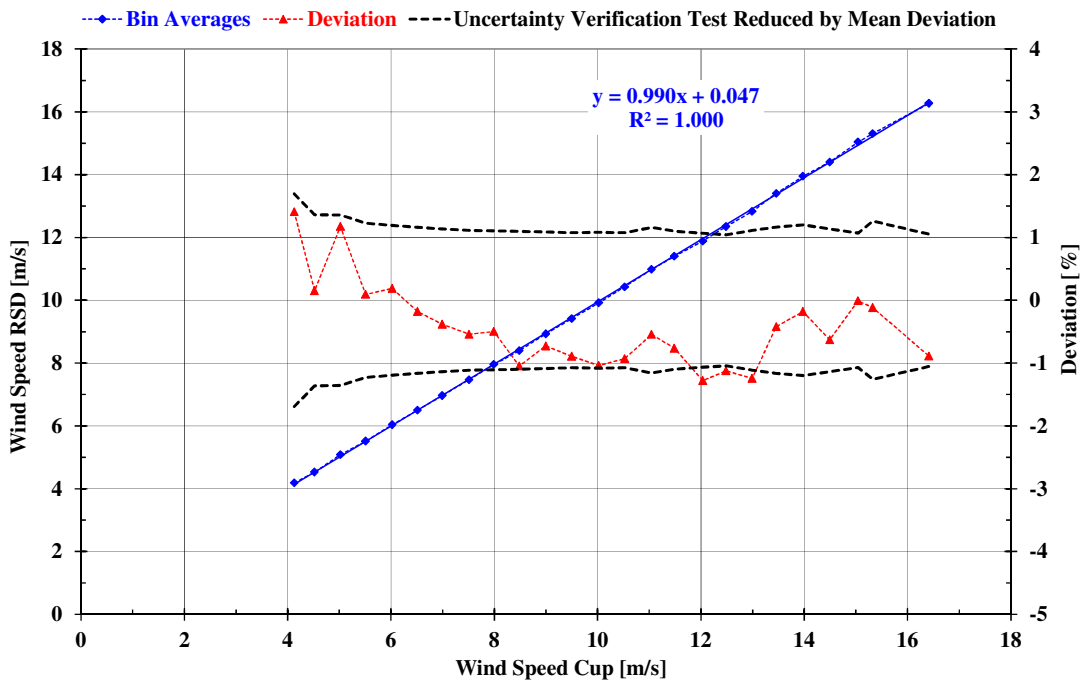


Figure 4.12 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 81.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.127	4.185	8	4.434	4.021	0.140	0.050	0.058	3.39	0.140	4.41	0.182
4.521	4.528	61	4.908	4.121	0.171	0.022	0.007	2.73	0.123	2.74	0.124
5.023	5.082	100	6.696	4.643	0.298	0.030	0.059	2.72	0.136	3.59	0.180
5.508	5.513	158	6.130	4.879	0.185	0.015	0.005	2.46	0.135	2.46	0.136
6.025	6.036	151	6.650	5.572	0.200	0.016	0.011	2.38	0.144	2.41	0.145
6.515	6.503	152	6.963	6.110	0.192	0.016	-0.012	2.32	0.151	2.35	0.153
6.993	6.967	156	7.512	6.550	0.213	0.017	-0.027	2.27	0.159	2.39	0.167
7.511	7.471	144	8.004	6.924	0.215	0.018	-0.041	2.22	0.167	2.47	0.186
7.994	7.954	116	8.482	7.454	0.227	0.021	-0.040	2.21	0.177	2.42	0.194
8.484	8.395	86	8.897	7.756	0.220	0.024	-0.089	2.19	0.186	3.03	0.257
8.997	8.931	60	9.403	8.421	0.228	0.029	-0.065	2.17	0.196	2.62	0.235
9.499	9.414	72	9.920	8.746	0.259	0.031	-0.085	2.15	0.204	2.80	0.265
10.024	9.920	40	10.629	9.232	0.267	0.042	-0.104	2.16	0.217	3.00	0.300
10.526	10.428	50	10.898	9.889	0.248	0.035	-0.098	2.15	0.226	2.84	0.299
11.044	10.985	30	11.638	10.351	0.336	0.061	-0.060	2.32	0.256	2.56	0.282
11.488	11.400	47	12.640	10.666	0.361	0.053	-0.088	2.20	0.252	2.68	0.308
12.036	11.882	30	12.562	11.350	0.254	0.046	-0.154	2.13	0.257	3.33	0.401
12.485	12.345	42	13.061	11.759	0.261	0.040	-0.140	2.09	0.261	3.07	0.383
12.993	12.832	18	13.282	12.249	0.278	0.066	-0.162	2.22	0.289	3.34	0.433
13.459	13.402	21	14.534	12.847	0.417	0.091	-0.056	2.33	0.313	2.48	0.333
13.974	13.948	15	14.643	13.487	0.407	0.105	-0.025	2.40	0.335	2.43	0.339
14.494	14.403	17	15.126	13.815	0.363	0.088	-0.091	2.27	0.329	2.60	0.377
15.042	15.041	6	15.294	14.866	0.163	0.067	-0.001	2.14	0.322	2.14	0.322
15.328	15.311	8	15.939	14.875	0.369	0.130	-0.018	2.52	0.386	2.53	0.388
16.414	16.268	3	16.453	16.148	0.162	0.094	-0.146	2.11	0.346	2.76	0.453

Table 4.5 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 81.75 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 60.75 m Measurement Height

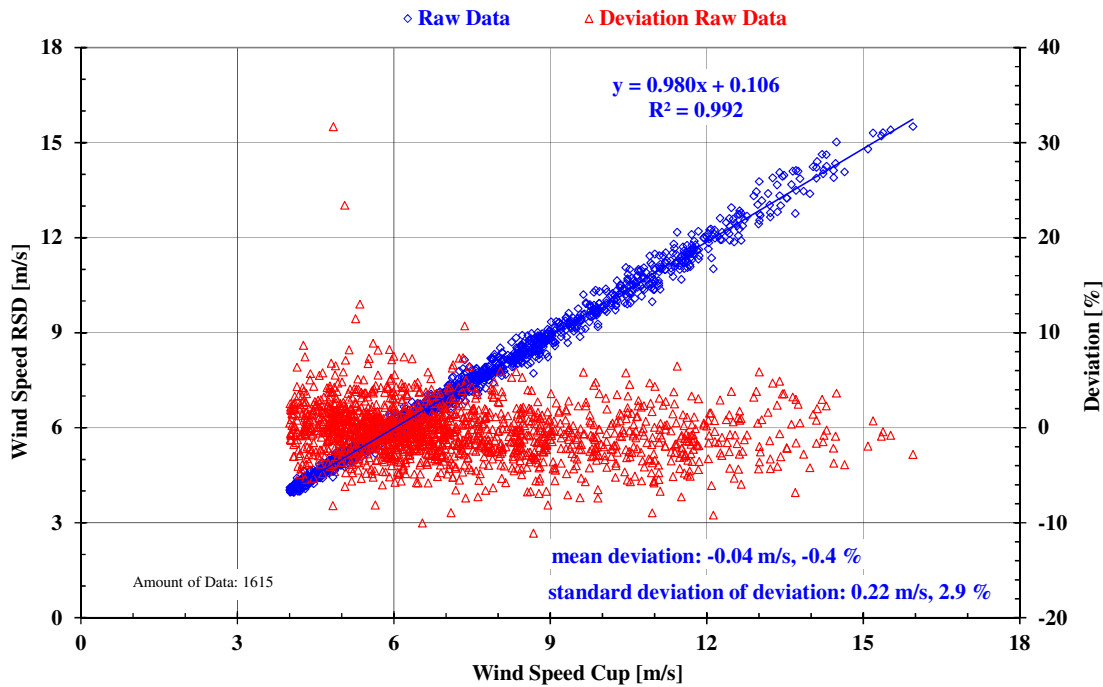


Figure 4.13 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 60.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

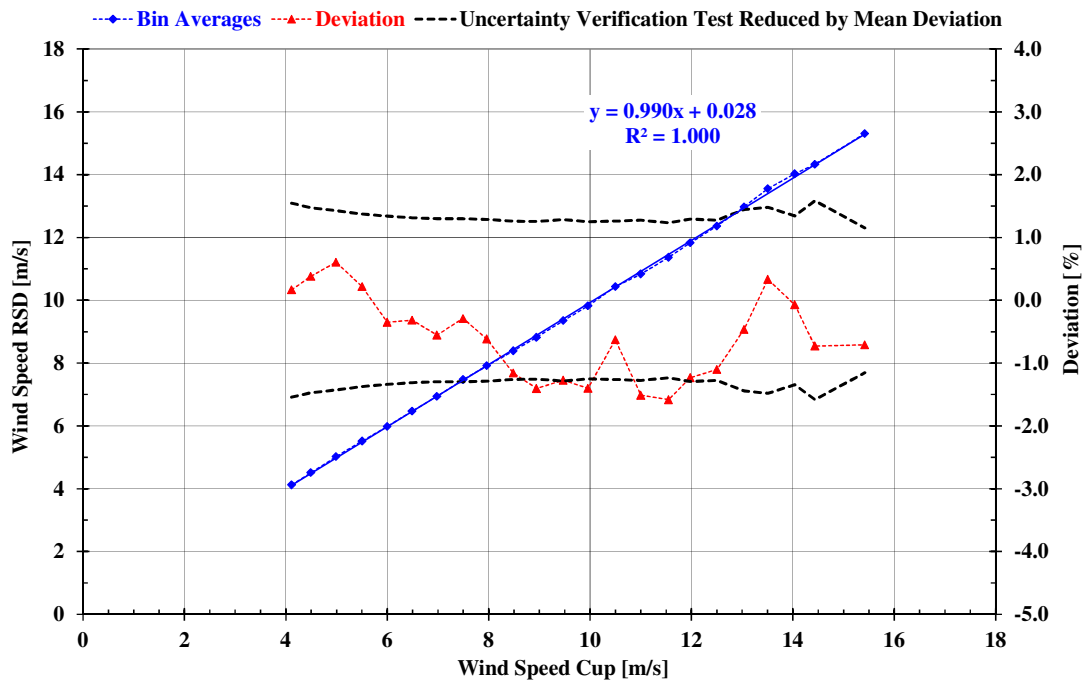


Figure 4.14 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.114	4.121	50	4.407	3.955	0.113	0.016	0.007	3.09	0.127	3.11	0.128
4.493	4.510	112	4.921	4.071	0.182	0.017	0.017	2.95	0.132	3.04	0.137
4.990	5.020	185	6.374	4.437	0.222	0.016	0.030	2.86	0.142	3.10	0.155
5.504	5.516	175	6.165	5.080	0.203	0.015	0.012	2.75	0.151	2.78	0.153
6.000	5.979	179	6.657	5.430	0.219	0.016	-0.021	2.68	0.161	2.77	0.166
6.491	6.471	150	7.059	5.890	0.210	0.017	-0.021	2.62	0.170	2.70	0.175
6.981	6.942	119	7.608	6.463	0.231	0.021	-0.039	2.59	0.181	2.82	0.197
7.495	7.473	90	8.144	6.830	0.259	0.027	-0.022	2.60	0.195	2.66	0.199
7.962	7.913	65	8.519	7.249	0.255	0.032	-0.049	2.58	0.205	2.86	0.227
8.486	8.387	88	8.981	7.715	0.253	0.027	-0.098	2.52	0.214	3.43	0.291
8.943	8.817	63	9.352	8.179	0.269	0.034	-0.126	2.51	0.225	3.77	0.337
9.471	9.351	39	10.199	8.675	0.294	0.047	-0.121	2.57	0.243	3.62	0.343
9.959	9.820	46	10.377	9.181	0.279	0.041	-0.140	2.50	0.249	3.76	0.374
10.499	10.433	44	11.054	9.848	0.327	0.049	-0.066	2.52	0.265	2.82	0.296
11.002	10.836	42	11.524	9.974	0.378	0.058	-0.166	2.55	0.281	3.96	0.435
11.548	11.365	46	12.171	10.678	0.306	0.045	-0.183	2.47	0.285	4.01	0.464
11.974	11.827	24	12.270	11.013	0.333	0.068	-0.148	2.58	0.310	3.57	0.428
12.503	12.365	24	12.946	11.862	0.330	0.067	-0.138	2.55	0.319	3.37	0.421
13.037	12.976	14	13.770	12.429	0.395	0.106	-0.061	2.89	0.376	3.03	0.395
13.506	13.551	15	14.116	12.763	0.465	0.120	0.045	2.96	0.400	3.03	0.410
14.038	14.028	11	14.631	13.386	0.371	0.112	-0.010	2.69	0.377	2.69	0.378
14.435	14.330	7	15.011	13.895	0.377	0.143	-0.105	3.17	0.457	3.49	0.503
15.417	15.308	3	15.400	15.209	0.096	0.055	-0.109	2.31	0.355	2.71	0.417

Table 4.6 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 60.75 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 40.75 m Measurement Height

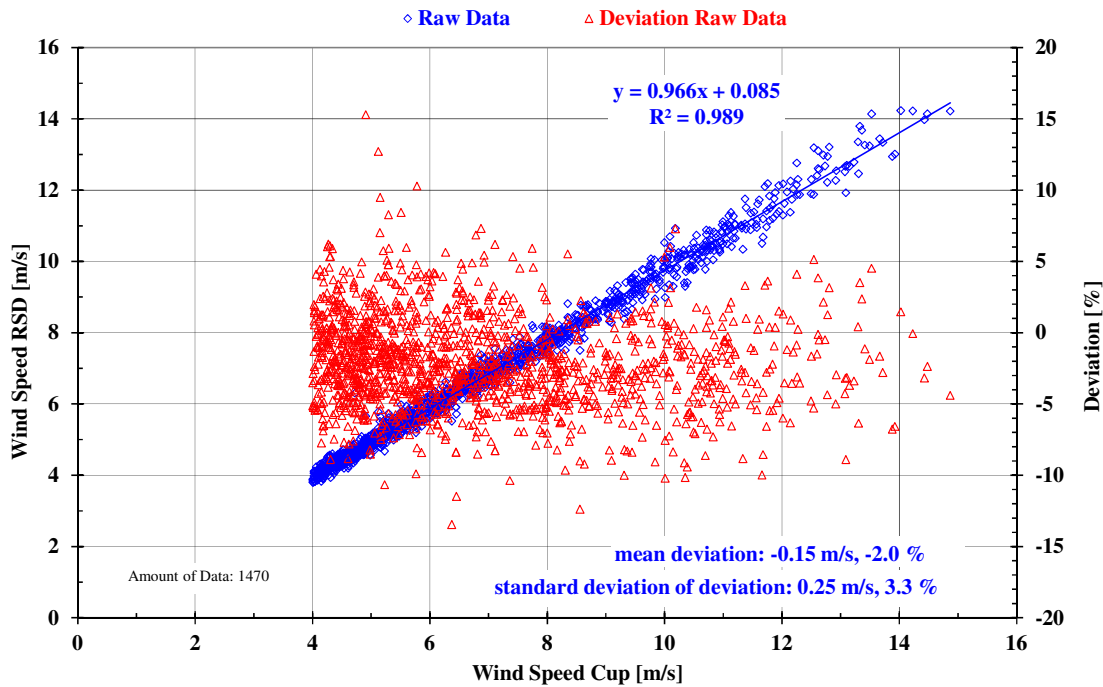


Figure 4.15 Scatter plot of horizontal wind speed component as measured by RSD against cup anemometer readings at 40.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

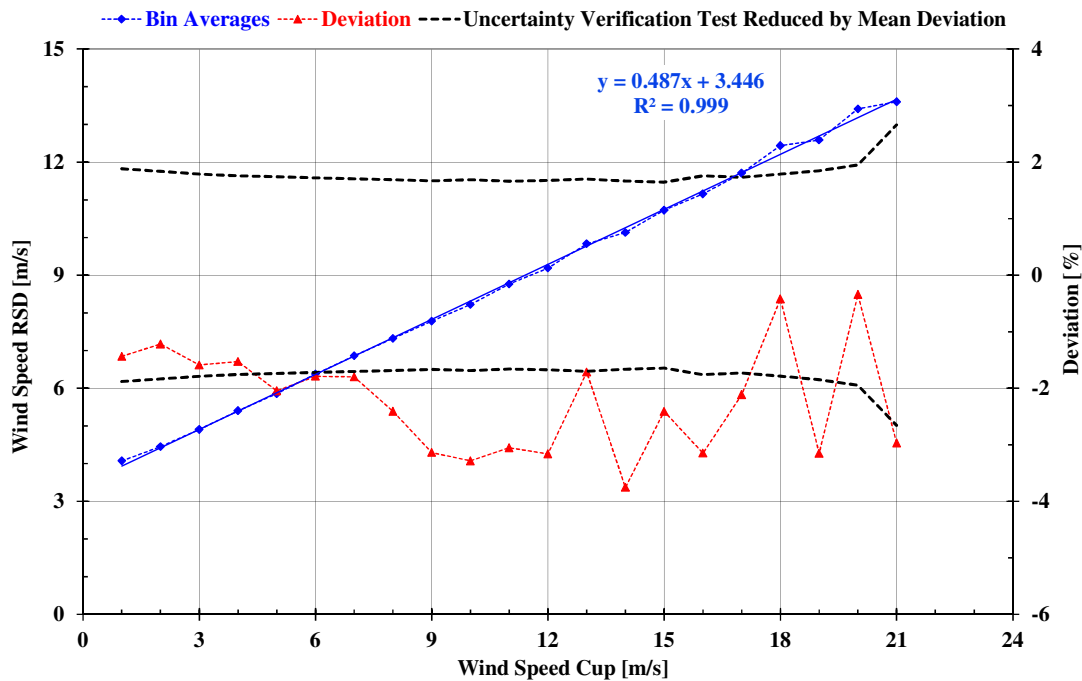


Figure 4.16 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 40.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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]
4.129	4.070	80	4.383	3.801	0.147	0.016	-0.059	3.76	0.155	4.74	0.196
4.503	4.448	189	6.301	3.927	0.223	0.016	-0.055	3.67	0.165	4.41	0.198
4.984	4.904	184	5.776	4.470	0.233	0.017	-0.079	3.58	0.178	4.78	0.238
5.485	5.401	140	5.974	4.917	0.215	0.018	-0.084	3.52	0.193	4.66	0.256
5.977	5.855	116	6.469	5.194	0.251	0.023	-0.122	3.48	0.208	5.37	0.321
6.493	6.377	105	7.051	5.516	0.275	0.027	-0.116	3.44	0.223	4.97	0.322
6.986	6.860	99	7.550	6.233	0.268	0.027	-0.126	3.41	0.238	4.96	0.347
7.500	7.319	81	8.204	6.603	0.256	0.028	-0.181	3.38	0.253	5.88	0.441
8.030	7.778	86	8.210	7.187	0.234	0.025	-0.252	3.34	0.268	7.11	0.571
8.499	8.220	58	8.812	7.500	0.315	0.041	-0.279	3.38	0.287	7.39	0.628
9.041	8.764	42	9.318	8.280	0.249	0.038	-0.276	3.32	0.300	6.95	0.629
9.486	9.187	46	9.853	8.380	0.334	0.049	-0.300	3.35	0.318	7.15	0.679
10.003	9.832	48	10.928	8.946	0.404	0.058	-0.172	3.40	0.340	4.83	0.483
10.527	10.131	44	10.882	9.299	0.350	0.053	-0.395	3.33	0.350	8.22	0.865
10.989	10.724	42	11.372	10.040	0.312	0.048	-0.265	3.29	0.361	5.84	0.641
11.516	11.154	23	12.098	10.335	0.411	0.086	-0.363	3.52	0.405	7.21	0.831
11.959	11.706	19	12.256	11.147	0.358	0.082	-0.253	3.46	0.414	5.46	0.653
12.490	12.437	15	13.190	11.871	0.453	0.117	-0.053	3.57	0.446	3.67	0.458
12.994	12.585	11	13.209	11.924	0.355	0.107	-0.410	3.70	0.480	7.31	0.950
13.457	13.411	9	14.138	12.460	0.463	0.154	-0.046	3.90	0.524	3.96	0.532
14.016	13.600	4	14.231	12.938	0.723	0.361	-0.416	5.32	0.745	7.97	1.117

Table 4.7 Bin analysis of 10-minute averages of the horizontal wind speed component measured by RSD against cup anemometer measurements at 40.75 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 pleasurable to good correlations from about 0.85 to 0.91 (Figure 4.17, Figure 4.19, Figure 4.21, Figure 4.23 and Figure 4.25). The square of the correlation coefficient is about 0.9 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 very good correlation with a squared correlation coefficient of more than 0.99 for measurement height between 40 m and 135 m.
- For wind shear between 100m – 135m the bin analysed exponents determined by the RSD and the cup anemometers agree well in an essentially range of shear exponents from about 0 to 0.55. Wind shears between 100m – 40m show less consensus.
- The standard deviation of the mean shear exponents gained by RSD in tendency slightly decrease with increasing measurement height from 0.04 to -0.016.

In all height levels, the bin averaged difference in wind shear exponent between cup anemometers and RSD shows strong wind shear dependence. The RSD overestimates wind shear at low shear exponents and underestimates at high wind shears.

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 below 0.12 ($k=2$) for a shear range of 0.0 to 0.6 in all height ranges with the exception of wind shear between 140 m and 120 m. This is considered as good. For negative wind shear and high wind shear above 0.6 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 134.75 m and 120.75 m

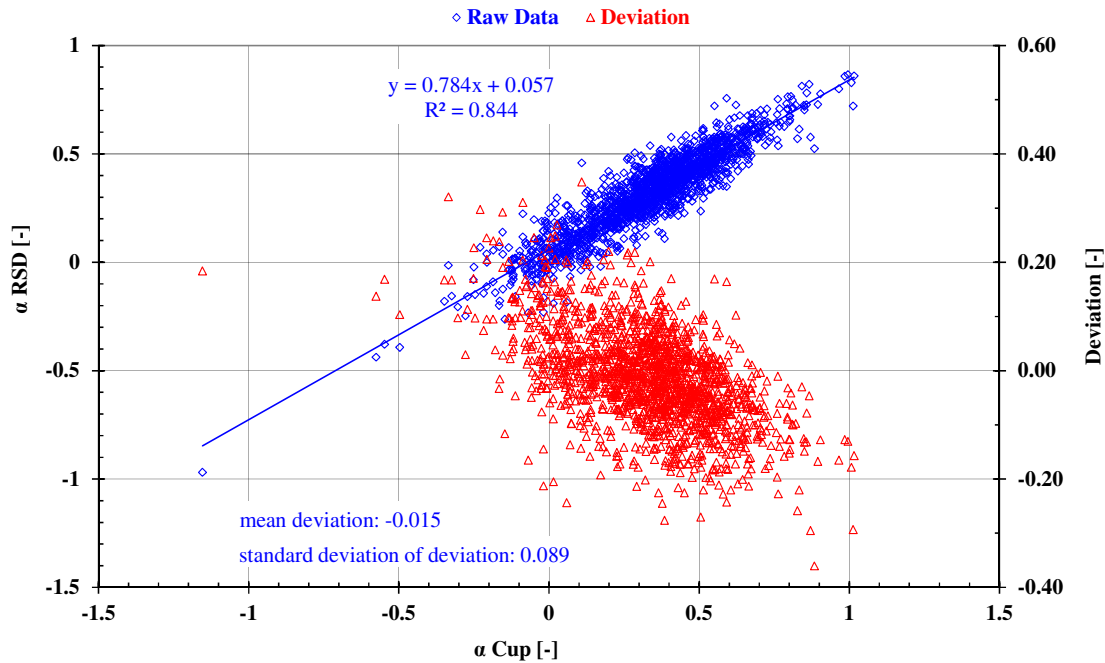


Figure 4.17: Scatter plot of shear exponents as measured by RSD between 134.75 m and 120.75 m height against cup anemometer measurements between 135 m and 120.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

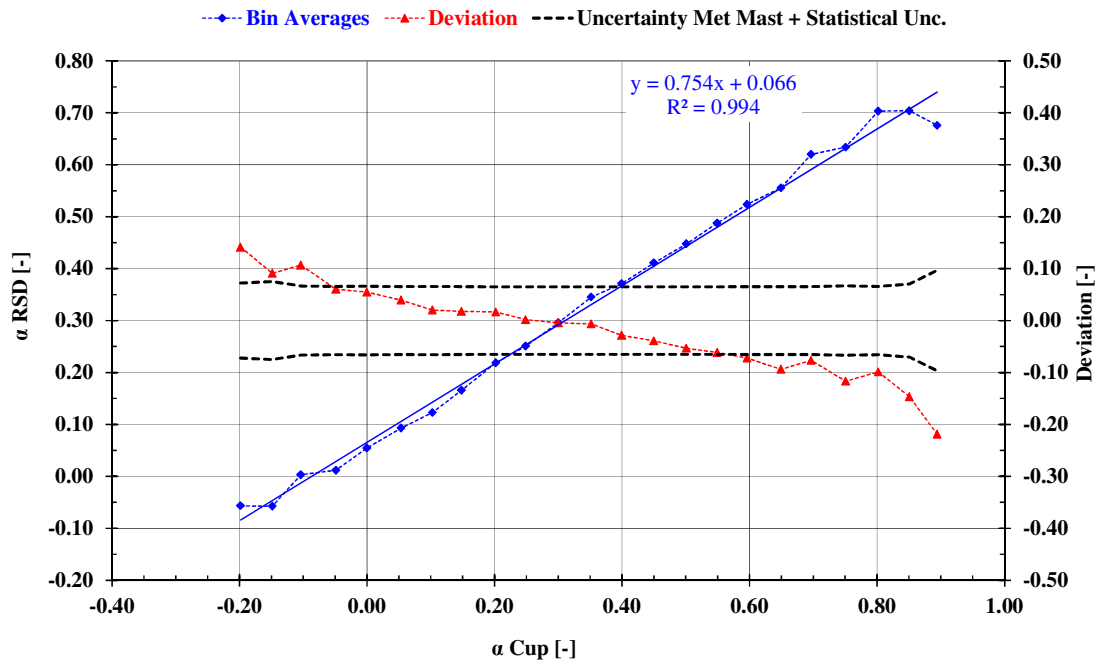


Figure 4.18: Bin analysis of shear exponents measured by RSD between 134.75 m and 120.75 m against cup anemometer measurements between 135 m and 120.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
-	-	-	-	-	-	-	-	-
-0.302	-0.204	3	-0.157	-0.249	0.046	0.040	0.098	0.248
-0.249	-0.069	5	0.069	-0.158	0.094	0.037	0.181	0.391
-0.198	-0.057	7	0.054	-0.143	0.085	0.032	0.142	0.318
-0.148	-0.057	11	0.138	-0.263	0.128	0.038	0.091	0.236
-0.104	0.003	22	0.223	-0.159	0.080	0.015	0.107	0.252
-0.049	0.012	40	0.196	-0.234	0.078	0.012	0.060	0.178
0.000	0.055	57	0.269	-0.231	0.105	0.014	0.055	0.172
0.053	0.093	76	0.296	-0.185	0.080	0.009	0.039	0.152
0.103	0.123	56	0.458	-0.037	0.082	0.011	0.020	0.137
0.148	0.166	80	0.329	-0.021	0.078	0.009	0.018	0.135
0.202	0.218	95	0.419	0.039	0.074	0.008	0.017	0.134
0.249	0.251	125	0.481	0.051	0.076	0.006	0.002	0.130
0.300	0.296	144	0.504	0.079	0.079	0.007	-0.004	0.130
0.352	0.345	168	0.538	0.140	0.074	0.006	-0.006	0.130
0.400	0.371	177	0.577	0.108	0.076	0.006	-0.028	0.142
0.450	0.411	143	0.584	0.214	0.071	0.006	-0.039	0.151
0.501	0.448	124	0.617	0.235	0.071	0.006	-0.053	0.168
0.549	0.488	107	0.721	0.336	0.069	0.007	-0.062	0.179
0.596	0.524	64	0.756	0.349	0.076	0.009	-0.072	0.195
0.649	0.555	50	0.677	0.420	0.059	0.008	-0.094	0.229
0.697	0.620	31	0.701	0.539	0.039	0.008	-0.077	0.201
0.751	0.634	14	0.752	0.536	0.064	0.017	-0.117	0.269
0.802	0.703	14	0.764	0.625	0.043	0.011	-0.099	0.237
0.851	0.704	10	0.820	0.569	0.091	0.028	-0.147	0.326
0.894	0.676	3	0.776	0.523	0.134	0.072	-0.219	0.478
1.003	0.826	5	0.865	0.720	0.061	0.030	-0.177	0.383

Table 4.8: Bin analysis of shear exponents measured by RSD between 134.75 m and 120.75 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 134.75 m and 100.75 m

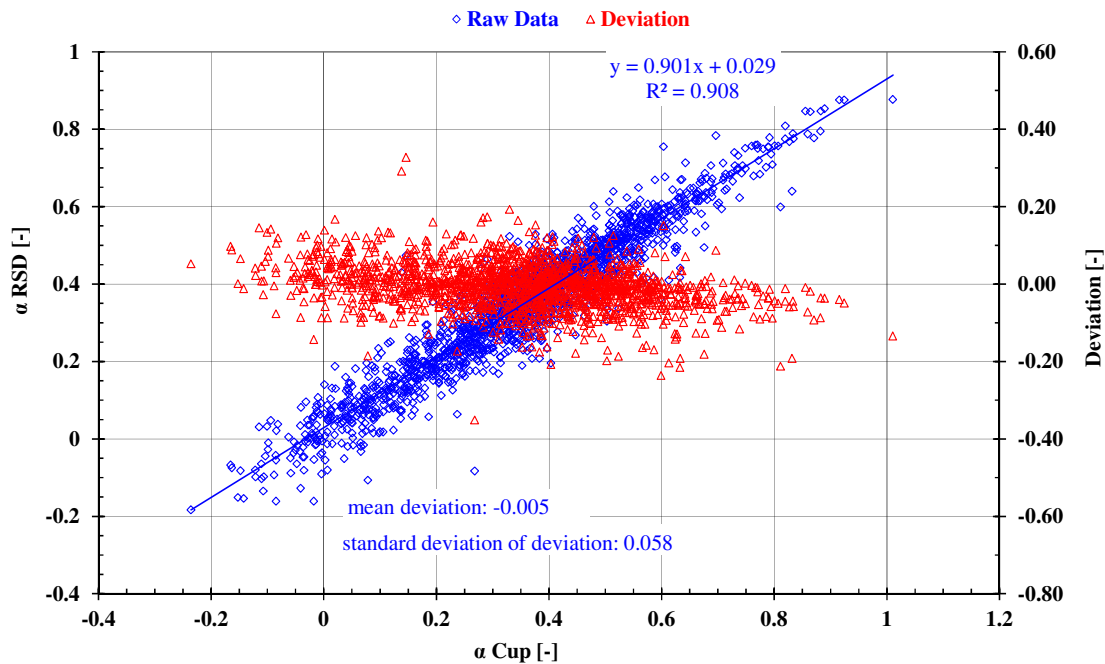


Figure 4.19: Scatter plot of shear exponents as measured by RSD between 134.75 m and 100.75 m height against cup anemometer measurements between 135 m and 100.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

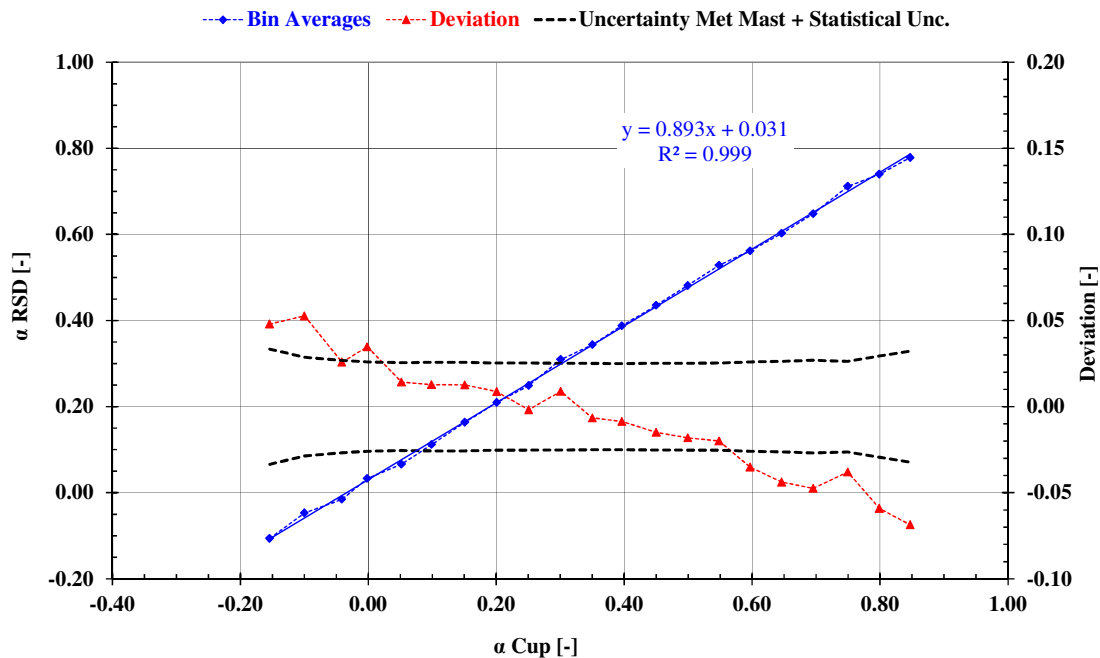


Figure 4.20: Bin analysis of shear exponents measured by RSD between 134.75 m and 100.75 m against cup anemometer measurements between 135 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.154	-0.106	5	-0.068	-0.154	0.043	0.023	0.048	0.117
-0.100	-0.047	18	0.048	-0.161	0.063	0.014	0.053	0.120
-0.041	-0.015	23	0.096	-0.128	0.053	0.010	0.026	0.075
-0.002	0.033	54	0.187	-0.161	0.062	0.008	0.035	0.087
0.052	0.066	66	0.181	-0.051	0.050	0.006	0.014	0.058
0.099	0.112	71	0.251	-0.107	0.061	0.007	0.013	0.057
0.151	0.164	85	0.473	0.052	0.066	0.007	0.013	0.057
0.201	0.209	89	0.354	0.057	0.050	0.005	0.009	0.054
0.251	0.249	125	0.383	-0.083	0.061	0.005	-0.002	0.051
0.301	0.310	162	0.464	0.168	0.060	0.004	0.009	0.053
0.350	0.344	191	0.523	0.189	0.059	0.004	-0.007	0.052
0.396	0.388	227	0.529	0.196	0.056	0.004	-0.009	0.053
0.450	0.435	149	0.570	0.268	0.053	0.004	-0.015	0.059
0.499	0.481	136	0.639	0.304	0.052	0.004	-0.018	0.062
0.548	0.529	112	0.649	0.402	0.046	0.004	-0.020	0.064
0.597	0.562	65	0.755	0.363	0.057	0.007	-0.035	0.087
0.646	0.603	44	0.713	0.417	0.058	0.008	-0.044	0.102
0.695	0.648	26	0.784	0.494	0.055	0.010	-0.047	0.109
0.750	0.712	18	0.760	0.623	0.038	0.008	-0.038	0.092
0.799	0.740	12	0.808	0.599	0.053	0.015	-0.059	0.132
0.847	0.779	8	0.847	0.640	0.064	0.020	-0.069	0.152
0.899	0.849	5	0.876	0.795	0.033	0.010	-0.050	0.113

Table 4.9: Bin analysis of shear exponents measured by RSD between 134.75 m and 100.75 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 120.75 m and 100.75 m

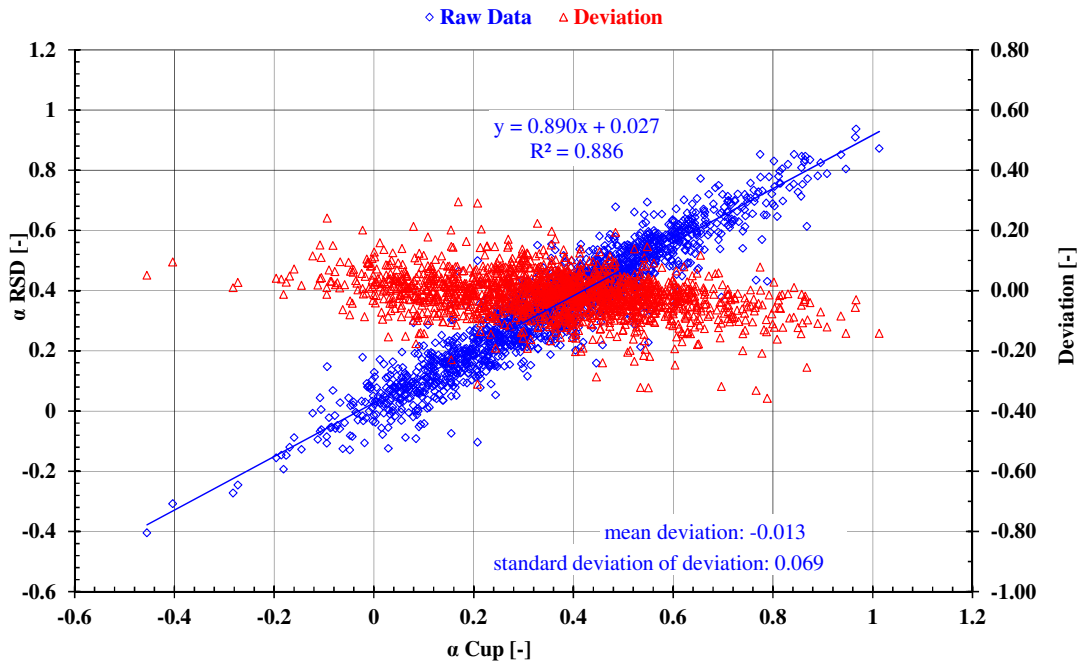


Figure 4.21: Scatter plot of shear exponents as measured by RSD between 120.75 m and 100.75 m height against cup anemometer measurements between 120.3 m and 100.3 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

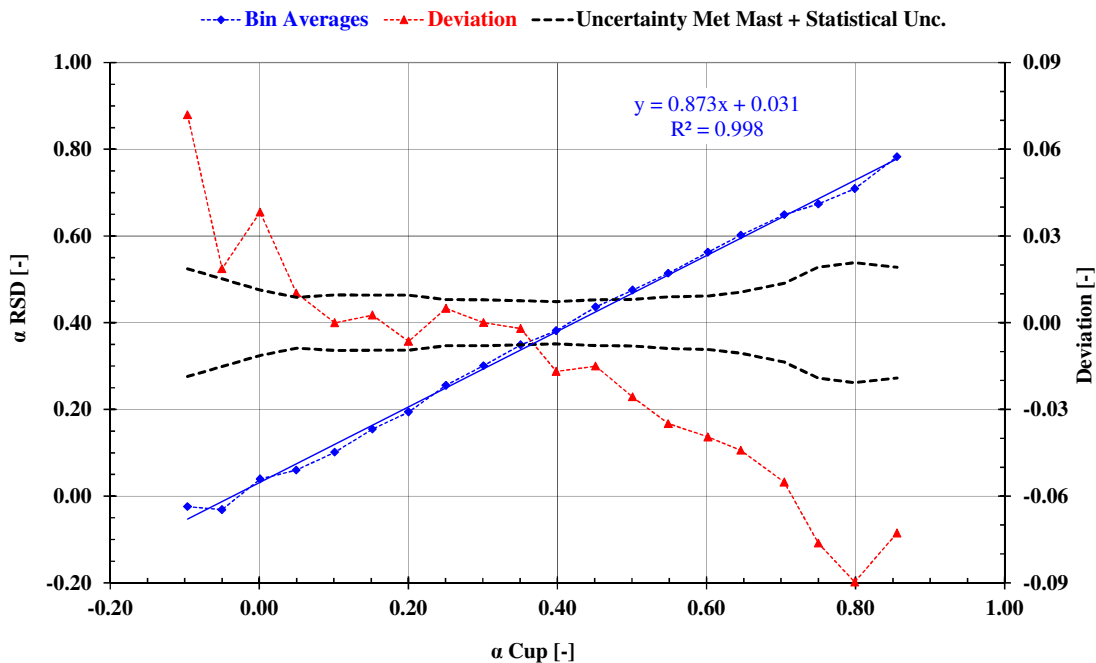


Figure 4.22: Bin analysis of shear exponents measured by RSD between 120.75 m and 100.75 m against cup anemometer measurements between 120.3 m and 100.3 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.184	-0.161	4	-0.147	-0.194	0.022	0.012	0.024	0.054
-0.158	-0.112	3	-0.088	-0.127	0.021	0.016	0.046	0.097
-0.096	-0.024	15	0.147	-0.108	0.068	0.018	0.072	0.149
-0.050	-0.031	15	0.044	-0.129	0.056	0.014	0.019	0.048
0.001	0.039	42	0.178	-0.106	0.063	0.010	0.038	0.080
0.050	0.060	67	0.196	-0.124	0.057	0.007	0.010	0.027
0.101	0.101	80	0.293	-0.092	0.074	0.008	0.000	0.019
0.152	0.155	85	0.464	-0.075	0.074	0.008	0.003	0.020
0.200	0.194	91	0.499	-0.103	0.075	0.008	-0.006	0.023
0.250	0.255	123	0.440	0.053	0.067	0.006	0.005	0.019
0.301	0.301	139	0.439	0.116	0.067	0.006	0.000	0.016
0.351	0.349	165	0.554	0.187	0.066	0.005	-0.002	0.016
0.398	0.382	194	0.553	0.202	0.062	0.004	-0.017	0.037
0.451	0.436	149	0.587	0.159	0.064	0.005	-0.015	0.034
0.501	0.475	134	0.678	0.287	0.061	0.005	-0.026	0.054
0.549	0.514	120	0.694	0.213	0.073	0.006	-0.035	0.072
0.602	0.563	78	0.701	0.357	0.058	0.007	-0.040	0.081
0.646	0.602	53	0.772	0.469	0.062	0.008	-0.044	0.091
0.704	0.649	33	0.750	0.378	0.068	0.012	-0.055	0.114
0.750	0.674	21	0.852	0.434	0.084	0.018	-0.076	0.157
0.799	0.709	20	0.830	0.431	0.092	0.020	-0.090	0.184
0.856	0.783	15	0.853	0.613	0.067	0.018	-0.073	0.150
0.898	0.798	3	0.825	0.781	0.024	0.015	-0.100	0.203
0.954	0.875	4	0.937	0.804	0.059	0.024	-0.078	0.165

Table 4.10: Bin analysis of shear exponents measured by RSD between 120.75 m and 100.75 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 100.75 m and 81.75 m

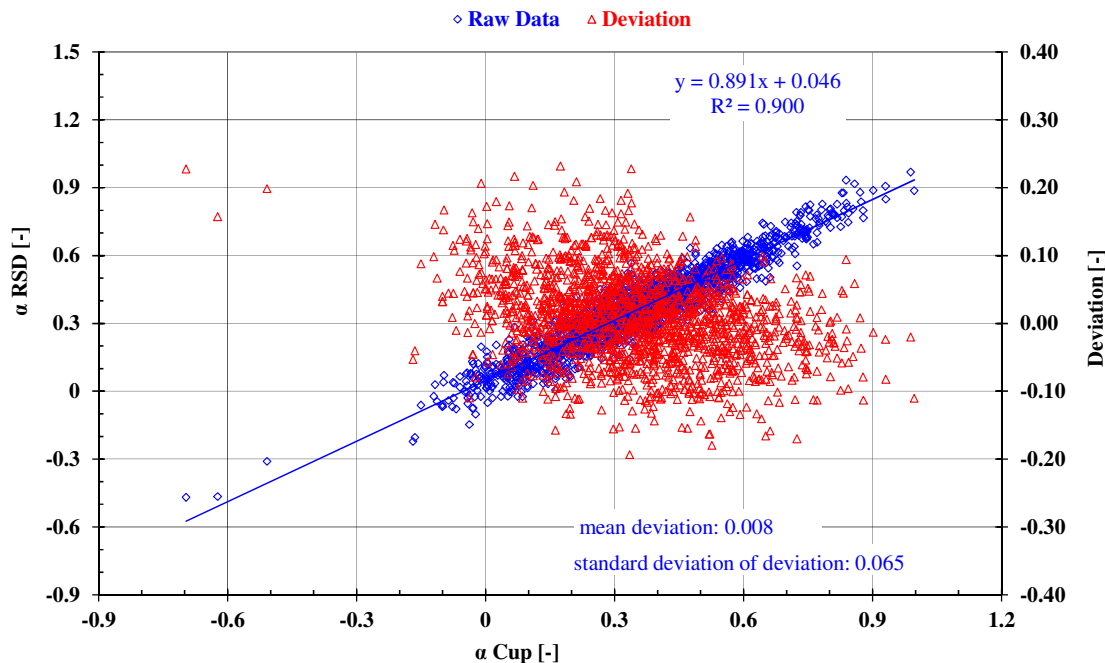


Figure 4.23: Scatter plot of shear exponents as measured by RSD between 100.75 m and 81.75 m height against cup anemometer measurements between 100.3 m and 82.2 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

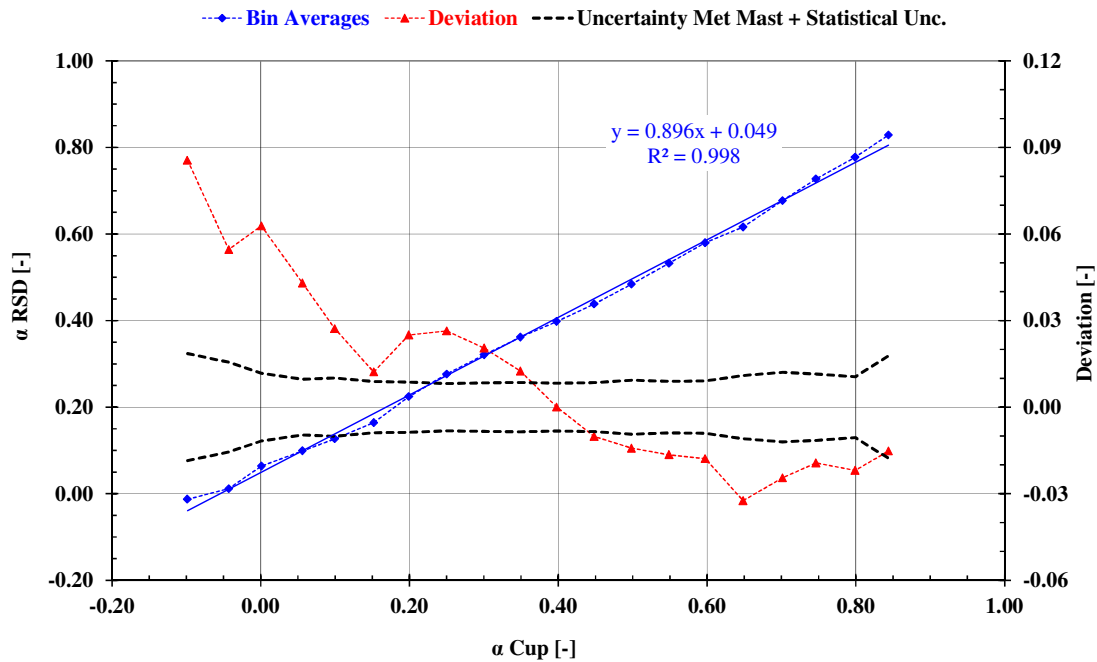


Figure 4.24: Bin analysis of shear exponents measured by RSD between 100.75 m and 81.75 m against cup anemometer measurements between 100.3 m and 82.2 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.161	-0.163	3	-0.062	-0.222	0.088	0.045	-0.002	0.091
-0.098	-0.013	10	0.071	-0.069	0.052	0.017	0.086	0.175
-0.043	0.012	24	0.132	-0.147	0.069	0.014	0.055	0.114
0.001	0.064	40	0.204	-0.102	0.063	0.010	0.063	0.128
0.056	0.099	72	0.284	-0.024	0.062	0.007	0.043	0.088
0.099	0.127	72	0.314	-0.024	0.069	0.008	0.027	0.058
0.152	0.164	110	0.406	0.005	0.064	0.006	0.012	0.030
0.199	0.224	133	0.420	0.055	0.067	0.006	0.025	0.053
0.250	0.276	147	0.451	0.142	0.061	0.005	0.026	0.055
0.300	0.321	171	0.497	0.142	0.069	0.005	0.020	0.044
0.349	0.362	161	0.567	0.142	0.067	0.005	0.012	0.030
0.398	0.398	158	0.537	0.249	0.063	0.005	0.000	0.017
0.448	0.438	135	0.587	0.303	0.057	0.005	-0.010	0.026
0.498	0.484	104	0.632	0.345	0.063	0.006	-0.014	0.034
0.549	0.533	114	0.660	0.346	0.056	0.005	-0.017	0.038
0.597	0.580	74	0.681	0.451	0.046	0.005	-0.018	0.040
0.648	0.616	52	0.744	0.486	0.060	0.008	-0.032	0.068
0.702	0.677	33	0.791	0.554	0.056	0.009	-0.024	0.055
0.747	0.727	34	0.824	0.650	0.048	0.008	-0.019	0.045
0.799	0.777	18	0.827	0.724	0.030	0.007	-0.022	0.049
0.844	0.829	14	0.932	0.727	0.062	0.016	-0.015	0.047
0.886	0.818	3	0.888	0.766	0.063	0.029	-0.068	0.150

Table 4.11: Bin analysis of shear exponents measured by RSD between 100.75 m and 81.75 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 81.75 m and 60.75 m

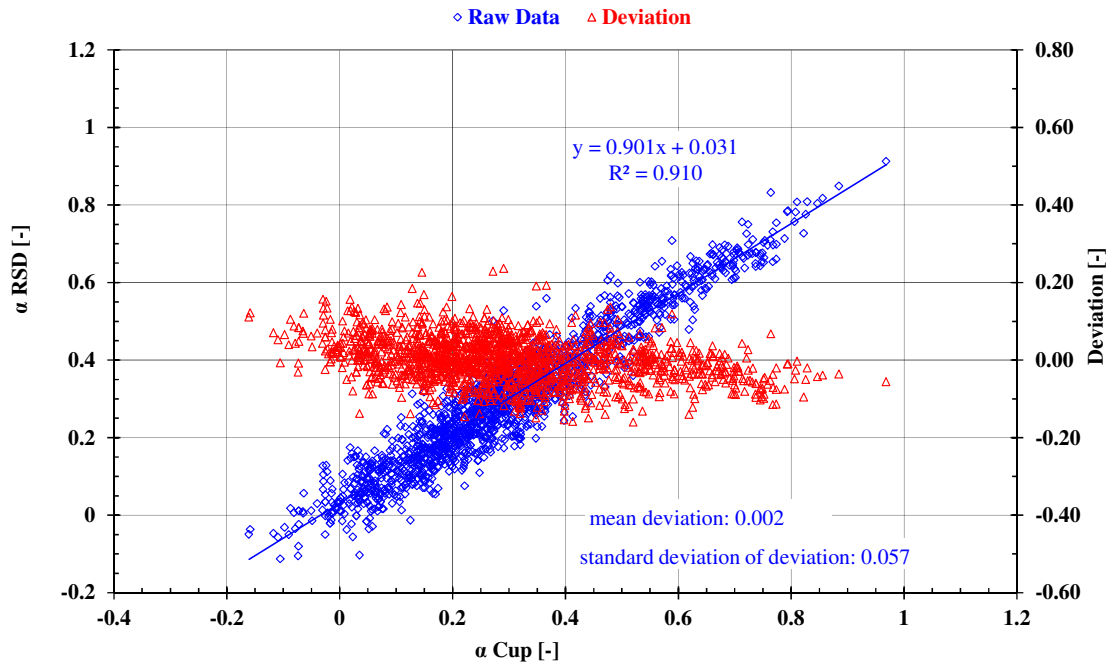


Figure 4.25: Scatter plot of shear exponents as measured by RSD between 81.75 m and 60.75 m height against cup anemometer measurements between 82.2 m and 60.4 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

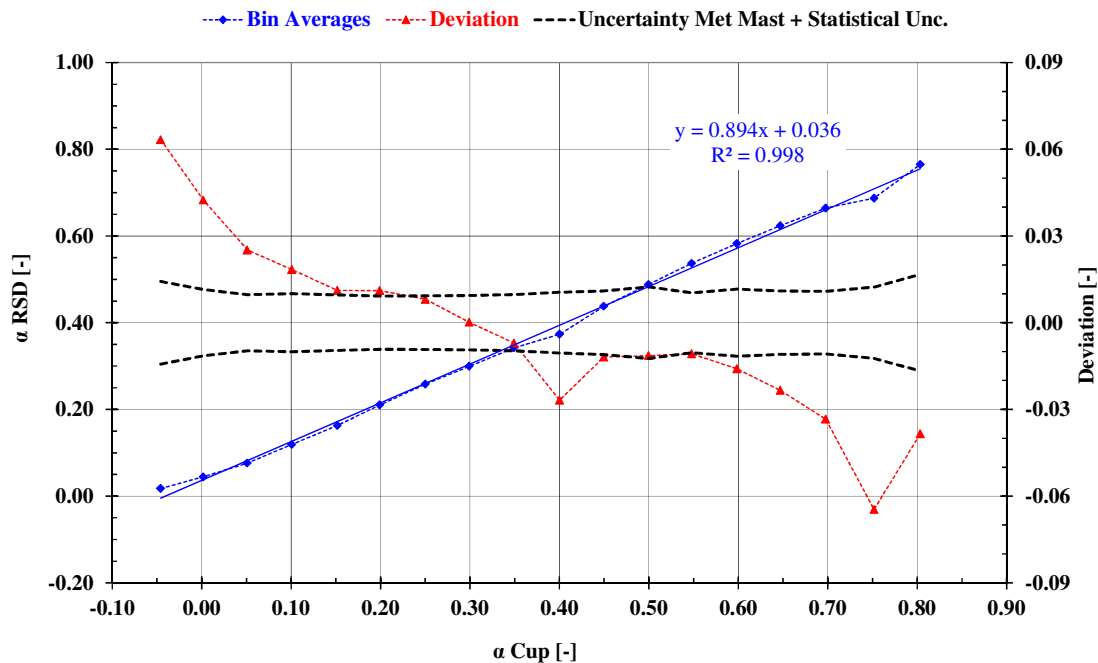


Figure 4.26: Bin analysis of shear exponents measured by RSD between 81.75 m and 60.75 m against cup anemometer measurements between 82.2 m and 60.4 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.096	-0.039	8	0.018	-0.113	0.040	0.012	0.057	0.118
-0.046	0.017	19	0.127	-0.105	0.059	0.012	0.063	0.130
0.002	0.044	44	0.175	-0.056	0.053	0.008	0.042	0.088
0.051	0.076	102	0.166	-0.103	0.049	0.005	0.025	0.054
0.101	0.119	88	0.252	0.013	0.053	0.006	0.018	0.042
0.152	0.163	151	0.372	-0.013	0.059	0.005	0.011	0.030
0.199	0.210	176	0.363	0.075	0.051	0.004	0.011	0.029
0.250	0.258	198	0.501	0.109	0.058	0.004	0.008	0.025
0.299	0.299	197	0.528	0.173	0.055	0.004	0.000	0.019
0.349	0.342	160	0.559	0.198	0.059	0.005	-0.007	0.024
0.400	0.373	82	0.533	0.244	0.055	0.006	-0.027	0.058
0.450	0.438	82	0.566	0.292	0.062	0.007	-0.012	0.032
0.500	0.488	58	0.617	0.360	0.059	0.008	-0.011	0.034
0.548	0.537	70	0.655	0.405	0.044	0.005	-0.011	0.030
0.598	0.582	41	0.708	0.479	0.045	0.007	-0.016	0.039
0.647	0.623	41	0.697	0.504	0.042	0.006	-0.023	0.052
0.698	0.664	37	0.756	0.607	0.034	0.005	-0.033	0.070
0.752	0.687	25	0.832	0.641	0.041	0.008	-0.065	0.132
0.803	0.765	7	0.808	0.713	0.034	0.014	-0.038	0.084
0.839	0.801	4	0.817	0.776	0.018	0.006	-0.038	0.080

Table 4.12: Bin analysis of shear exponents measured by RSD between 81.75 m and 60.75 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 60.75 m and 40.75 m

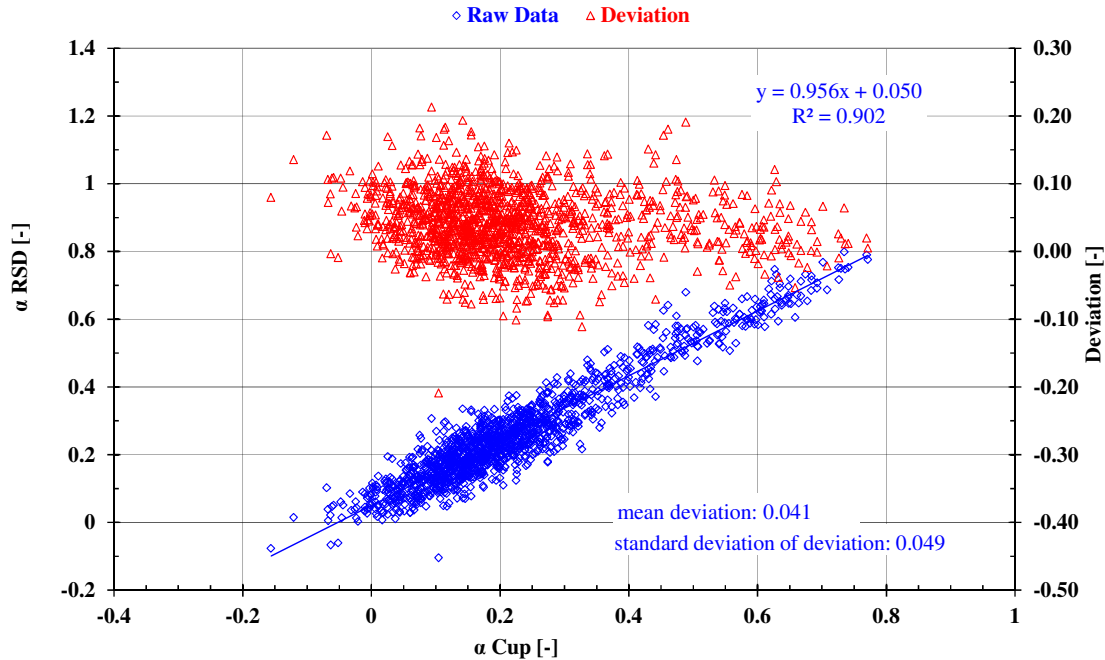


Figure 4.27: Scatter plot of shear exponents as measured by RSD between 60.75 m and 40.75 m height against cup anemometer measurements between 82.2 m and 60.4 m height and the deviation between both shear exponents. Each point represents a 10-minute period.

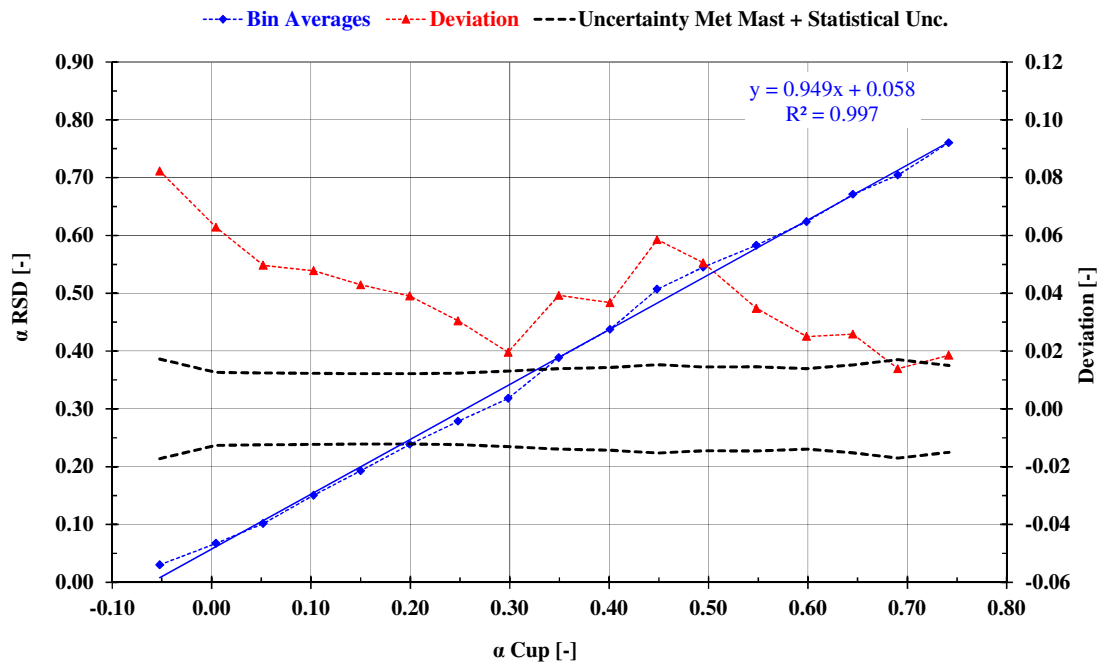


Figure 4.28: Bin analysis of shear exponents measured by RSD between 60.75 m and 40.75 m against cup anemometer measurements between 82.2 m and 60.4 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

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)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
-0.052	0.030	14	0.102	-0.066	0.047	0.013	0.082	0.168
0.004	0.067	50	0.137	0.002	0.035	0.005	0.063	0.128
0.052	0.102	115	0.216	0.011	0.044	0.004	0.050	0.102
0.103	0.150	201	0.307	-0.104	0.052	0.004	0.048	0.099
0.150	0.193	279	0.335	0.070	0.050	0.003	0.043	0.089
0.200	0.239	240	0.374	0.110	0.046	0.003	0.039	0.082
0.248	0.278	185	0.413	0.142	0.051	0.004	0.030	0.066
0.298	0.318	96	0.439	0.206	0.055	0.005	0.020	0.047
0.349	0.389	62	0.511	0.216	0.057	0.007	0.039	0.083
0.401	0.438	36	0.518	0.347	0.049	0.007	0.037	0.079
0.448	0.507	37	0.641	0.371	0.061	0.009	0.059	0.121
0.495	0.545	29	0.679	0.477	0.038	0.008	0.051	0.105
0.548	0.583	29	0.647	0.507	0.041	0.008	0.035	0.075
0.599	0.624	29	0.712	0.578	0.036	0.006	0.025	0.057
0.645	0.671	24	0.748	0.594	0.039	0.008	0.026	0.060
0.690	0.704	8	0.768	0.654	0.034	0.011	0.014	0.044
0.742	0.760	8	0.799	0.717	0.027	0.008	0.019	0.048

Table 4.13: Bin analysis of shear exponents measured by RSD between 60.75 m and 40.75 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.

4.4 Accuracy of RSD in Terms of Turbulence Intensity

For the evaluation of the accuracy of the turbulence intensity of the horizontal wind speed component per 10-minute period as measured by RSD, the same data filtering as described in chapter 3.4 has been applied. Detailed results of the comparison at all measurement heights of the mast are shown for cup anemometers as references in the following sub chapters. Key results are:

- The correlation of the turbulence intensity as determined by the RSD and the turbulence intensity as determined from cup anemometers is pleasurable (squared correlation coefficient of about 0.76 to 0.88) Figure 4.29, Figure 4.33, Figure 4.35, Figure 4.37, Figure 4.39, Figure 4.41.
- The mean deviation of turbulence intensity determined by the RSD deviates between -0.006 to -0.009 from the reference measurements at the different measurement heights.
- The bin averages of the turbulence intensity as determined by the RSD correlate very good with the bin averages of the turbulence intensities determined with the reference sensors of the met mast with squared correlation coefficients of about 0.99.

4.4.1 Accuracy of RSD in Terms of Turbulence Intensity at 134.75 m Measurement Height

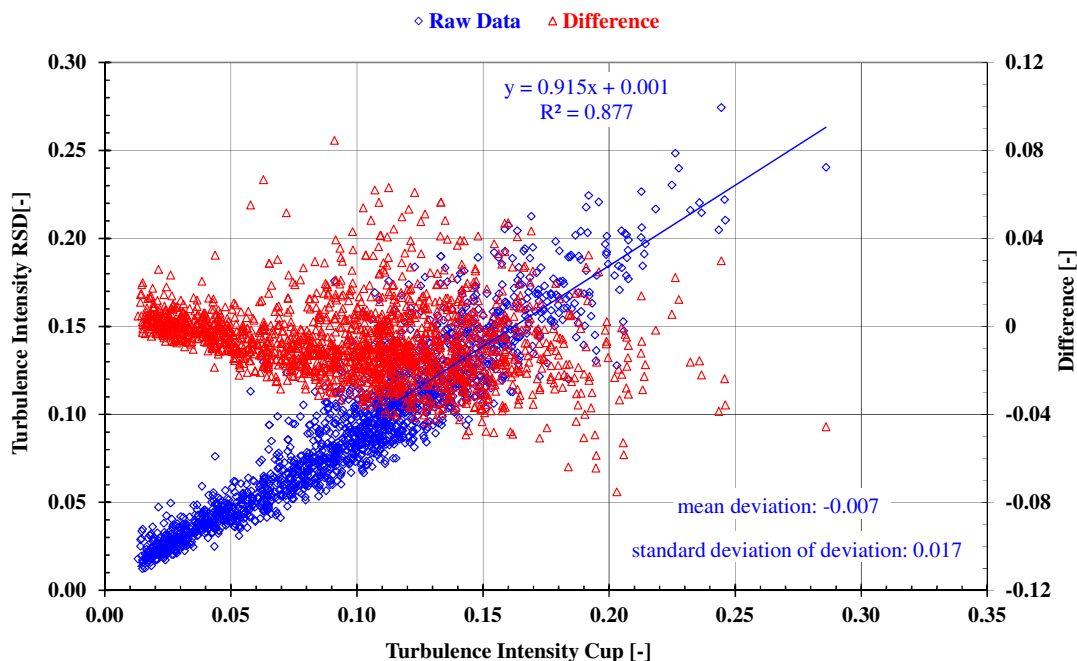


Figure 4.29 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 134.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

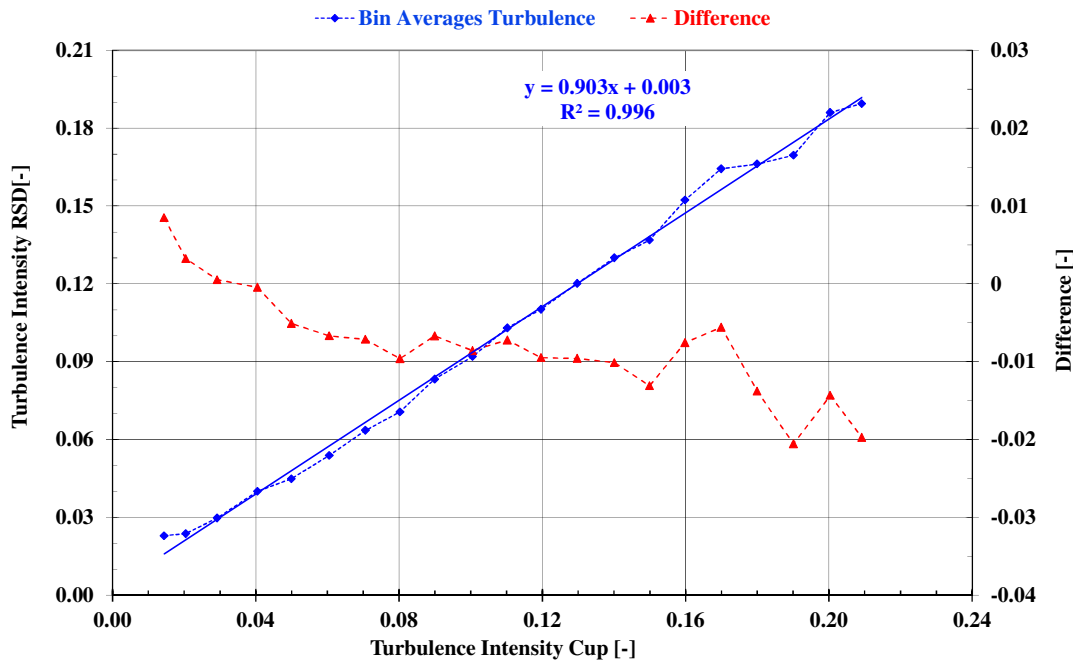


Figure 4.30: Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 134.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.014	0.023	8	0.034	0.012	0.007	0.003	0.009	0.063
0.020	0.024	101	0.047	0.013	0.006	0.001	0.003	0.060
0.029	0.030	113	0.050	0.020	0.005	0.000	0.001	0.060
0.040	0.040	99	0.076	0.025	0.007	0.001	0.000	0.060
0.050	0.045	86	0.062	0.031	0.006	0.001	-0.005	0.061
0.061	0.054	78	0.130	0.036	0.014	0.002	-0.007	0.062
0.071	0.063	87	0.124	0.041	0.014	0.001	-0.007	0.062
0.080	0.071	94	0.113	0.051	0.012	0.001	-0.010	0.063
0.090	0.083	130	0.176	0.057	0.018	0.002	-0.007	0.062
0.100	0.092	136	0.156	0.067	0.015	0.001	-0.009	0.062
0.110	0.103	194	0.176	0.070	0.019	0.001	-0.007	0.062
0.120	0.110	154	0.184	0.075	0.018	0.001	-0.009	0.063
0.130	0.120	121	0.190	0.084	0.020	0.002	-0.010	0.063
0.140	0.130	124	0.183	0.094	0.019	0.002	-0.010	0.063
0.150	0.137	83	0.192	0.103	0.019	0.002	-0.013	0.066
0.160	0.152	69	0.207	0.113	0.022	0.003	-0.008	0.062
0.170	0.164	37	0.213	0.122	0.019	0.003	-0.006	0.061
0.180	0.166	30	0.198	0.120	0.017	0.003	-0.014	0.066
0.190	0.170	25	0.224	0.130	0.026	0.005	-0.021	0.073
0.200	0.186	12	0.221	0.128	0.023	0.007	-0.014	0.068
0.209	0.189	16	0.227	0.147	0.020	0.005	-0.020	0.072
0.229	0.235	3	0.248	0.216	0.017	0.010	0.006	0.065
0.240	0.228	4	0.274	0.205	0.031	0.016	-0.012	0.071

Table 4.14 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 134.75 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.

4.4.2 Accuracy of RSD in Terms of Turbulence Intensity at 130.75 m Measurement Height

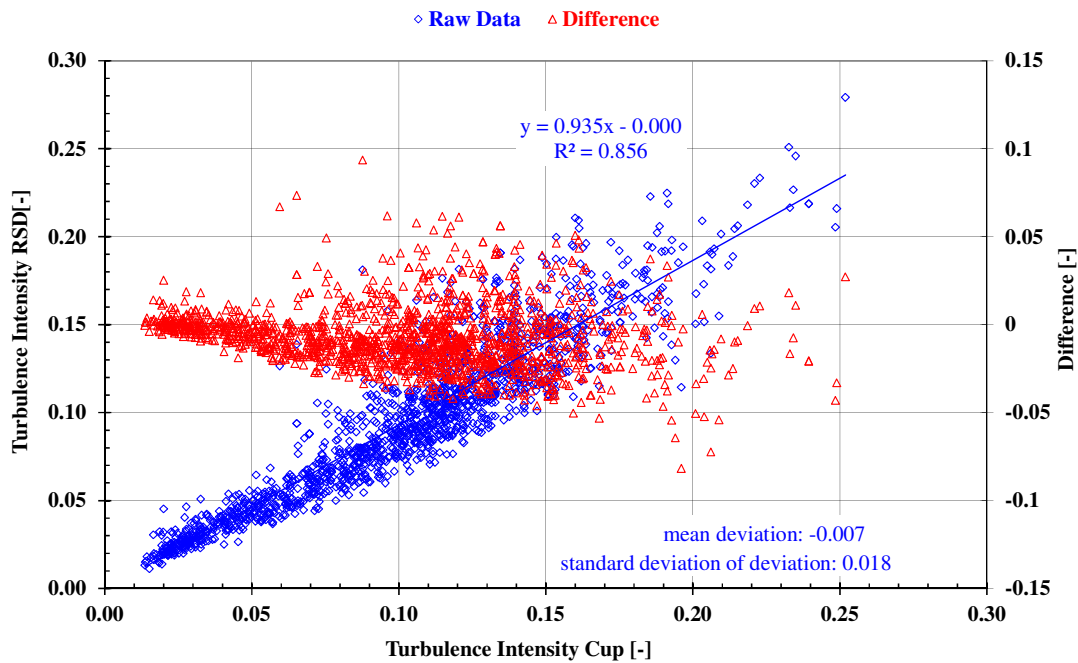


Figure 4.31 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 130.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

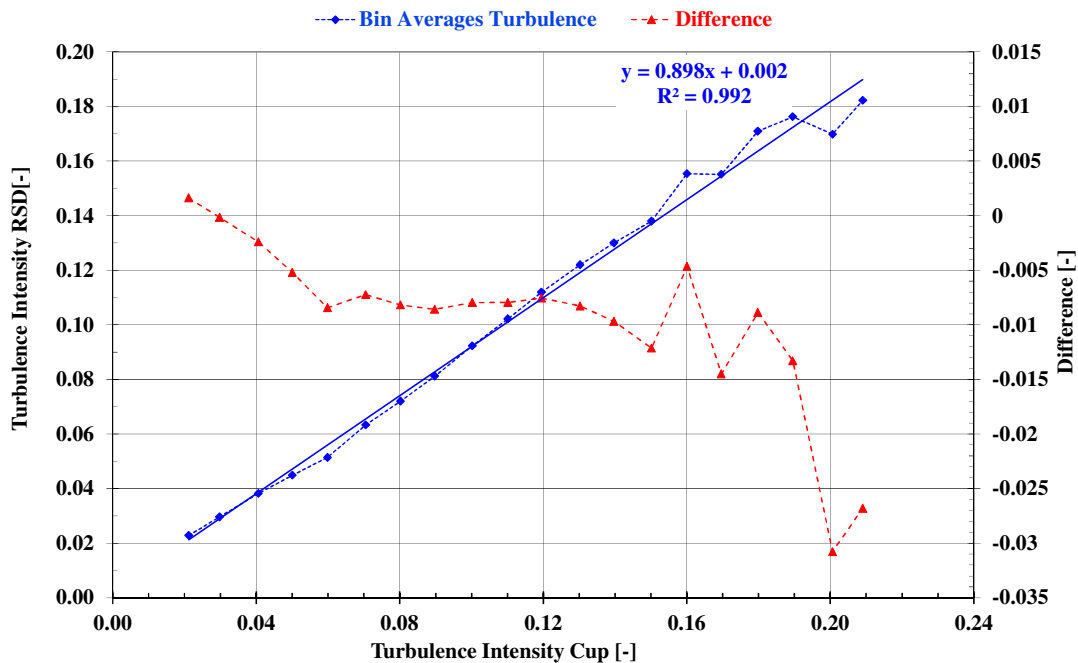


Figure 4.32 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 130.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.014	0.015	4	0.018	0.013	0.002	0.001	0.002	0.060
0.021	0.023	66	0.045	0.011	0.005	0.001	0.002	0.060
0.030	0.030	85	0.051	0.020	0.006	0.001	0.000	0.060
0.041	0.038	57	0.054	0.025	0.006	0.001	-0.002	0.060
0.050	0.045	69	0.065	0.026	0.006	0.001	-0.005	0.061
0.060	0.051	68	0.126	0.037	0.012	0.001	-0.008	0.062
0.071	0.063	77	0.139	0.044	0.015	0.002	-0.007	0.062
0.080	0.072	83	0.125	0.050	0.014	0.002	-0.008	0.062
0.090	0.081	110	0.181	0.054	0.017	0.002	-0.009	0.062
0.100	0.092	119	0.158	0.060	0.016	0.001	-0.008	0.062
0.110	0.102	163	0.176	0.071	0.019	0.002	-0.008	0.062
0.120	0.112	161	0.181	0.076	0.019	0.002	-0.008	0.062
0.130	0.122	108	0.191	0.089	0.023	0.002	-0.008	0.062
0.140	0.130	96	0.187	0.096	0.019	0.002	-0.010	0.063
0.150	0.138	84	0.200	0.101	0.020	0.002	-0.012	0.065
0.160	0.155	53	0.211	0.109	0.025	0.003	-0.005	0.061
0.170	0.155	30	0.197	0.115	0.019	0.003	-0.015	0.067
0.180	0.171	23	0.195	0.142	0.013	0.003	-0.009	0.063
0.190	0.176	24	0.225	0.130	0.027	0.006	-0.013	0.067
0.201	0.170	9	0.209	0.114	0.028	0.009	-0.031	0.088
0.209	0.182	10	0.204	0.134	0.022	0.007	-0.027	0.082
0.219	0.222	4	0.233	0.206	0.012	0.006	0.003	0.061
0.234	0.235	4	0.251	0.217	0.016	0.008	0.001	0.062
0.250	0.233	3	0.279	0.205	0.040	0.023	-0.016	0.081

Table 4.15 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 130.75 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.

4.4.3 Accuracy of RSD in Terms of Turbulence Intensity at 120.75 m Measurement Height

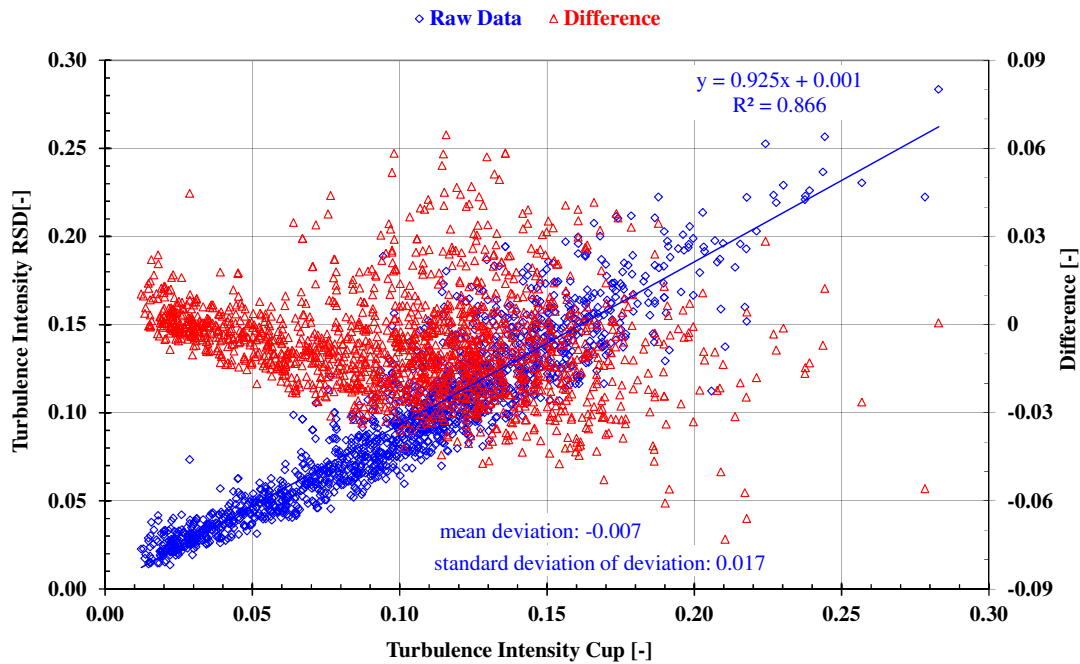


Figure 4.33 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 120.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

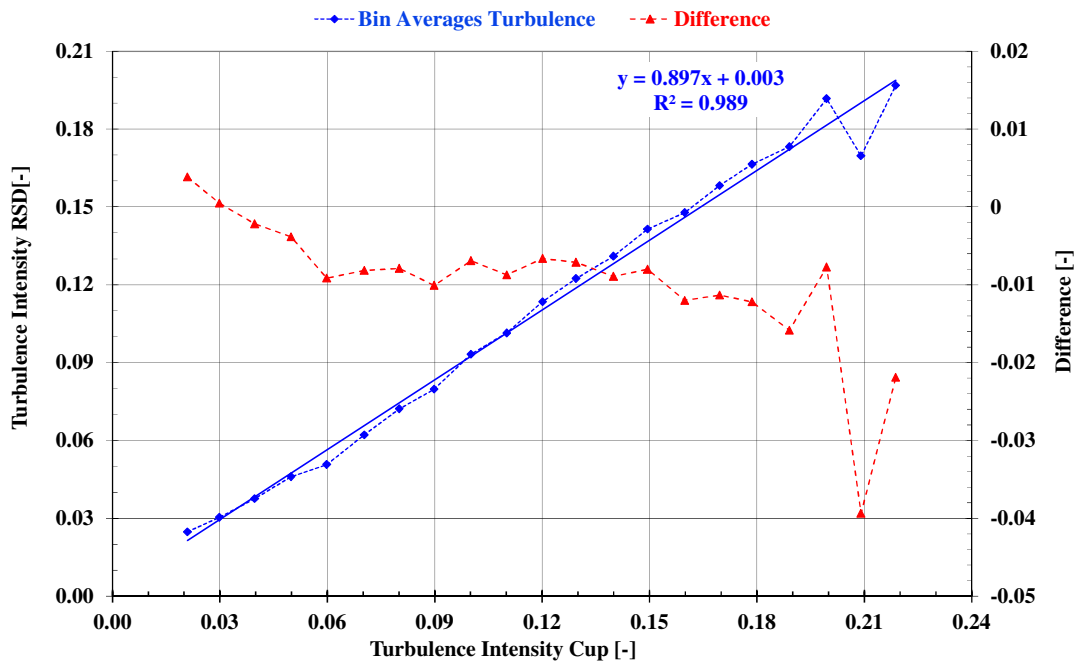


Figure 4.34 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 120.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.014	0.022	7	0.029	0.014	0.005	0.002	0.008	0.062
0.021	0.025	82	0.042	0.014	0.006	0.001	0.004	0.061
0.030	0.030	87	0.073	0.019	0.007	0.001	0.000	0.060
0.040	0.038	63	0.057	0.026	0.007	0.001	-0.002	0.060
0.050	0.046	67	0.063	0.031	0.007	0.001	-0.004	0.061
0.060	0.051	78	0.099	0.039	0.009	0.001	-0.009	0.063
0.070	0.062	70	0.105	0.045	0.011	0.001	-0.008	0.062
0.080	0.072	88	0.121	0.045	0.014	0.001	-0.008	0.062
0.090	0.080	103	0.189	0.054	0.018	0.002	-0.010	0.063
0.100	0.093	124	0.156	0.060	0.018	0.002	-0.007	0.062
0.110	0.101	159	0.173	0.070	0.018	0.001	-0.009	0.063
0.120	0.113	152	0.180	0.078	0.020	0.002	-0.007	0.062
0.129	0.122	147	0.187	0.081	0.020	0.002	-0.007	0.062
0.140	0.131	93	0.194	0.097	0.021	0.002	-0.009	0.063
0.149	0.141	96	0.186	0.107	0.019	0.002	-0.008	0.062
0.160	0.148	72	0.200	0.114	0.021	0.003	-0.012	0.065
0.170	0.158	49	0.211	0.117	0.021	0.003	-0.011	0.064
0.179	0.166	23	0.212	0.137	0.018	0.004	-0.012	0.065
0.189	0.173	21	0.222	0.129	0.026	0.006	-0.016	0.069
0.199	0.192	12	0.214	0.167	0.014	0.004	-0.008	0.062
0.209	0.170	8	0.198	0.112	0.031	0.011	-0.039	0.101
0.219	0.197	7	0.253	0.152	0.035	0.013	-0.022	0.078
0.240	0.233	5	0.257	0.221	0.015	0.007	-0.008	0.063

Table 4.16 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 120.75 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.

4.4.4 Accuracy of RSD in Terms of Turbulence Intensity at 100.75 m Measurement Height

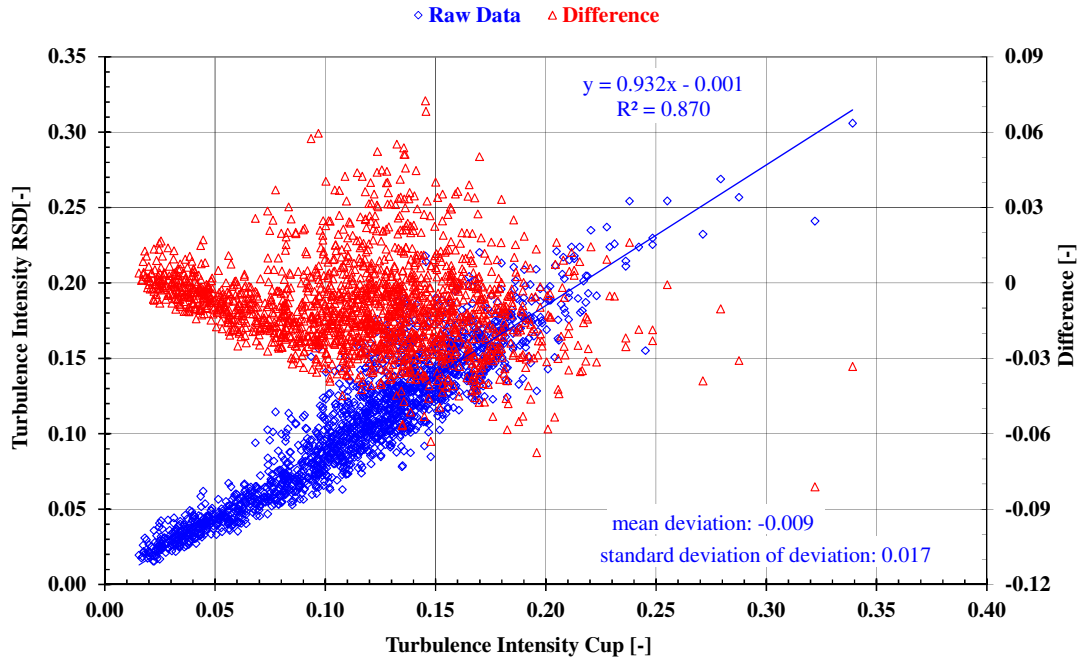


Figure 4.35 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 100.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

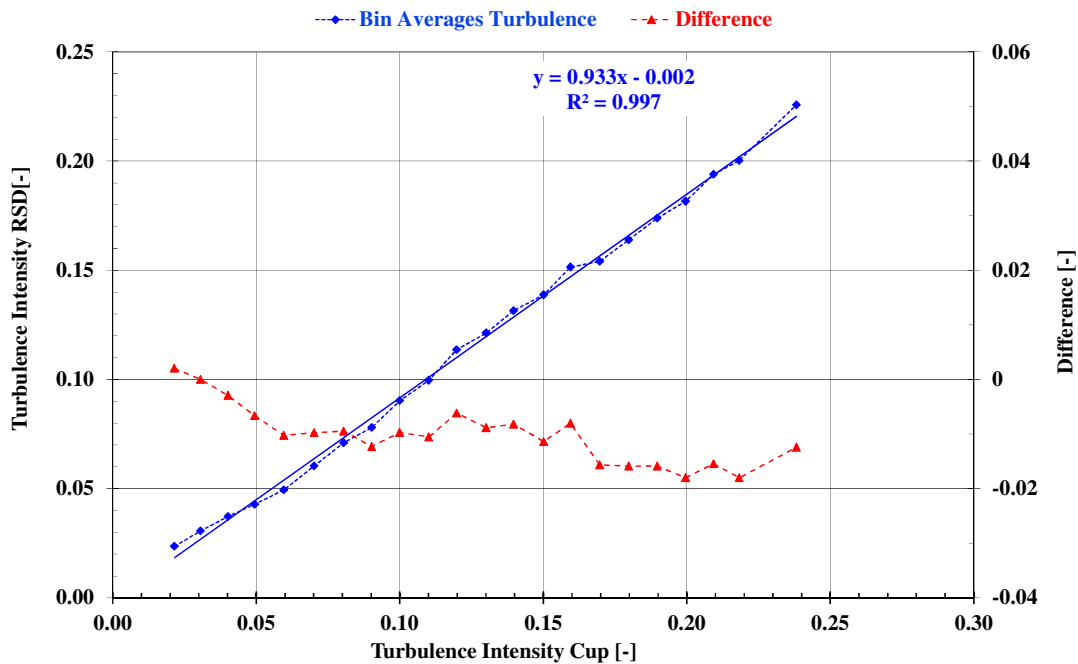


Figure 4.36 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 100.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.022	0.024	42	0.041	0.015	0.006	0.001	0.002	0.060
0.031	0.031	61	0.044	0.021	0.006	0.001	0.000	0.060
0.040	0.037	79	0.062	0.025	0.007	0.001	-0.003	0.060
0.049	0.043	60	0.057	0.033	0.005	0.001	-0.007	0.061
0.060	0.049	72	0.067	0.035	0.008	0.001	-0.010	0.063
0.070	0.060	57	0.102	0.045	0.012	0.002	-0.010	0.063
0.080	0.071	89	0.114	0.052	0.014	0.001	-0.009	0.063
0.090	0.078	75	0.151	0.053	0.016	0.002	-0.012	0.065
0.100	0.090	134	0.156	0.060	0.017	0.002	-0.010	0.063
0.110	0.100	137	0.158	0.063	0.018	0.001	-0.011	0.064
0.120	0.114	161	0.176	0.074	0.019	0.002	-0.006	0.061
0.130	0.121	176	0.188	0.078	0.020	0.002	-0.009	0.063
0.140	0.132	157	0.189	0.079	0.021	0.002	-0.008	0.062
0.150	0.139	118	0.218	0.085	0.022	0.002	-0.011	0.064
0.159	0.151	103	0.199	0.116	0.017	0.002	-0.008	0.062
0.170	0.154	92	0.220	0.122	0.020	0.002	-0.016	0.068
0.180	0.164	64	0.213	0.123	0.017	0.002	-0.016	0.068
0.190	0.174	37	0.210	0.133	0.019	0.003	-0.016	0.068
0.200	0.182	20	0.221	0.128	0.023	0.005	-0.018	0.071
0.209	0.194	17	0.224	0.162	0.020	0.005	-0.015	0.068

Table 4.17 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 100.75 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.

4.4.5 Accuracy of RSD in Terms of Turbulence Intensity at 81.75 m Measurement Height

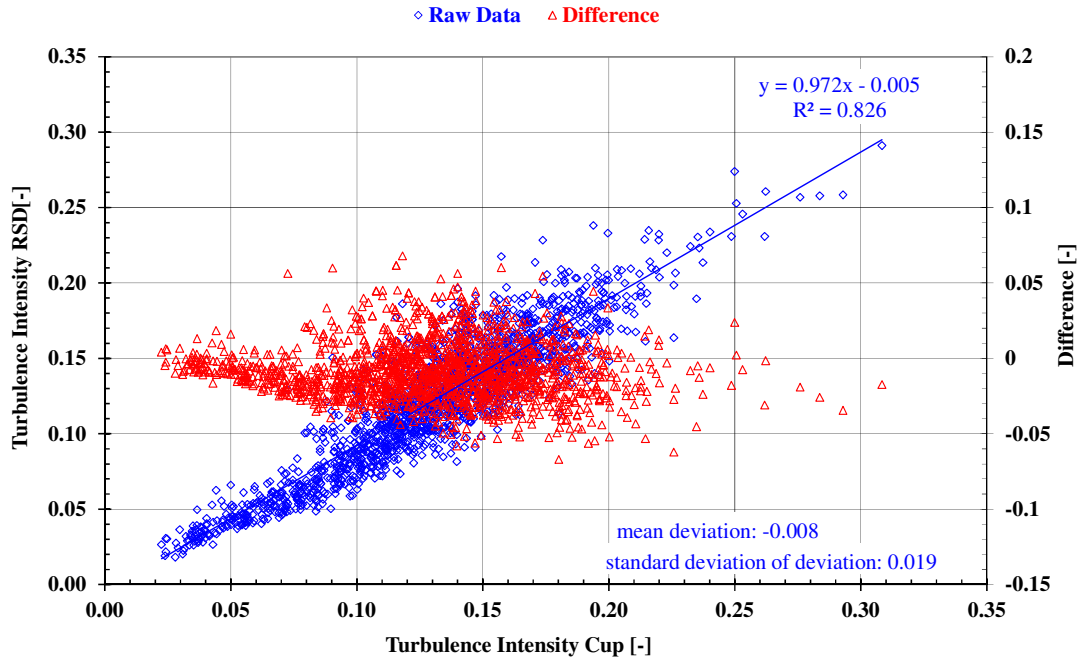


Figure 4.37 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 81.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

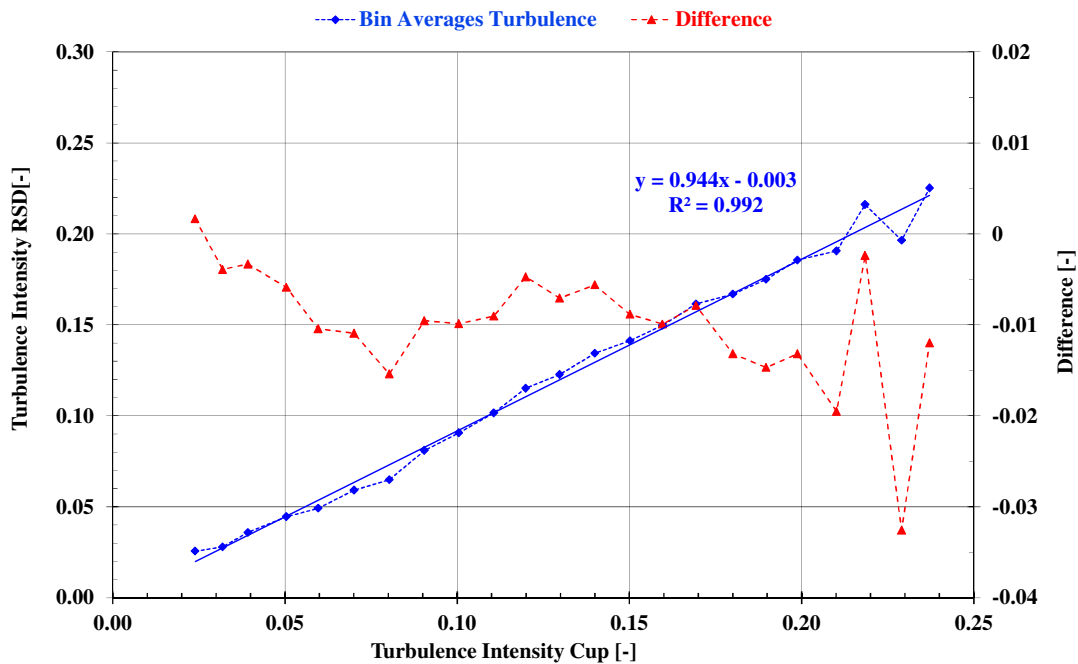


Figure 4.38 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 81.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.024	0.026	5	0.031	0.019	0.005	0.002	0.002	0.060
0.032	0.028	15	0.036	0.018	0.005	0.001	-0.004	0.061
0.039	0.036	35	0.063	0.026	0.008	0.001	-0.003	0.060
0.050	0.045	32	0.066	0.036	0.007	0.001	-0.006	0.061
0.060	0.049	40	0.067	0.039	0.007	0.001	-0.010	0.064
0.070	0.059	48	0.129	0.044	0.013	0.002	-0.011	0.064
0.080	0.065	63	0.105	0.049	0.013	0.002	-0.015	0.068
0.090	0.081	71	0.150	0.050	0.018	0.002	-0.010	0.063
0.100	0.091	95	0.143	0.059	0.018	0.002	-0.010	0.063
0.111	0.102	128	0.155	0.070	0.019	0.002	-0.009	0.063
0.120	0.115	155	0.186	0.073	0.020	0.002	-0.005	0.061
0.130	0.123	157	0.186	0.085	0.020	0.002	-0.007	0.062
0.140	0.134	176	0.196	0.082	0.022	0.002	-0.006	0.061
0.150	0.141	144	0.192	0.091	0.020	0.002	-0.009	0.063
0.160	0.150	117	0.217	0.103	0.020	0.002	-0.010	0.063
0.169	0.161	98	0.228	0.126	0.018	0.002	-0.008	0.062
0.180	0.167	79	0.209	0.113	0.021	0.002	-0.013	0.066
0.190	0.175	54	0.238	0.133	0.021	0.003	-0.015	0.067
0.199	0.186	36	0.233	0.148	0.017	0.003	-0.013	0.066
0.210	0.191	18	0.229	0.161	0.017	0.004	-0.020	0.072
0.218	0.216	9	0.235	0.193	0.014	0.005	-0.002	0.061
0.229	0.196	5	0.224	0.164	0.022	0.010	-0.033	0.091
0.237	0.225	4	0.234	0.214	0.009	0.004	-0.012	0.065
0.251	0.251	4	0.274	0.231	0.018	0.009	0.000	0.063

Table 4.18 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 81.75 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.

4.4.6 Accuracy of RSD in Terms of Turbulence Intensity at 60.75 m Measurement Height

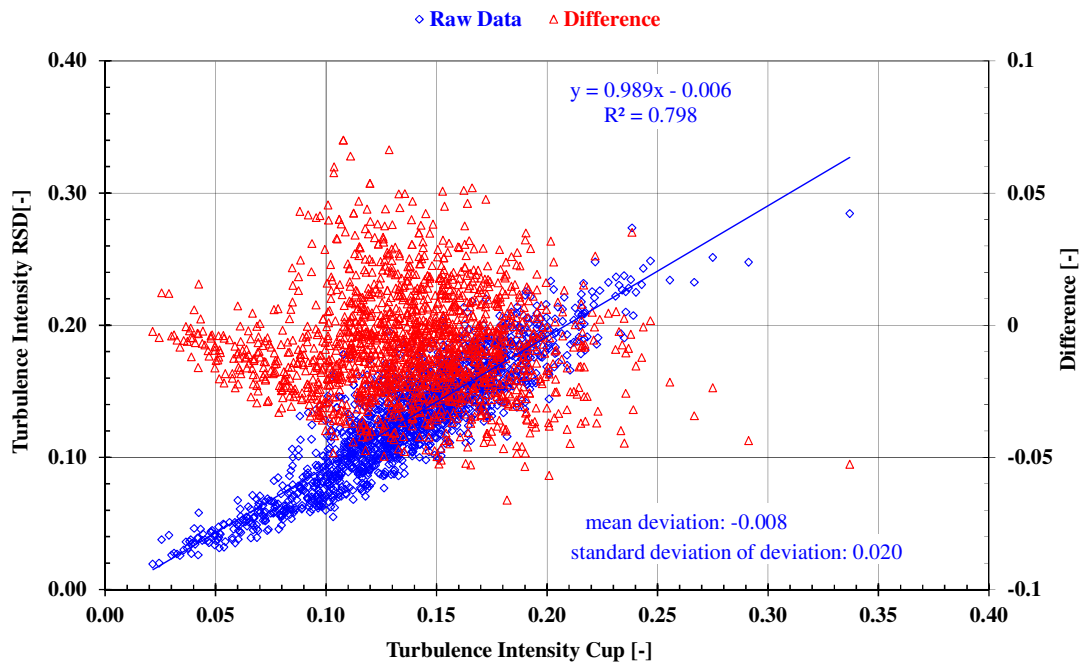


Figure 4.39 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 60.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

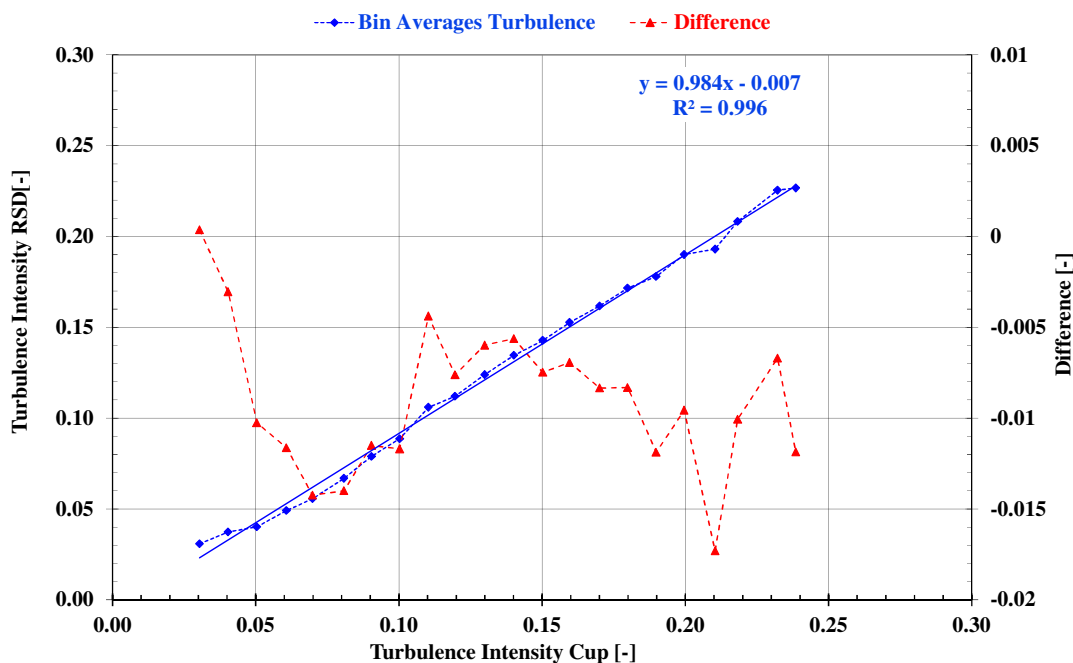


Figure 4.40 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 60.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.030	0.031	6	0.041	0.026	0.007	0.003	0.000	0.060
0.040	0.037	17	0.058	0.026	0.008	0.002	-0.003	0.060
0.050	0.040	21	0.050	0.031	0.005	0.001	-0.010	0.063
0.061	0.049	22	0.067	0.035	0.008	0.002	-0.012	0.064
0.070	0.056	36	0.071	0.039	0.009	0.001	-0.014	0.066
0.081	0.067	44	0.106	0.046	0.014	0.002	-0.014	0.066
0.090	0.079	49	0.134	0.058	0.018	0.003	-0.012	0.064
0.100	0.089	94	0.164	0.055	0.023	0.002	-0.012	0.065
0.110	0.106	111	0.178	0.068	0.022	0.002	-0.004	0.061
0.120	0.112	150	0.174	0.070	0.021	0.002	-0.008	0.062
0.130	0.124	169	0.195	0.077	0.021	0.002	-0.006	0.061
0.140	0.135	172	0.186	0.088	0.019	0.001	-0.006	0.061
0.150	0.143	158	0.203	0.098	0.021	0.002	-0.007	0.062
0.160	0.153	146	0.213	0.111	0.020	0.002	-0.007	0.062
0.170	0.162	130	0.220	0.113	0.019	0.002	-0.008	0.062
0.180	0.172	92	0.210	0.116	0.018	0.002	-0.008	0.062
0.190	0.178	73	0.225	0.136	0.021	0.002	-0.012	0.065
0.200	0.190	41	0.233	0.144	0.018	0.003	-0.010	0.063
0.210	0.193	17	0.221	0.166	0.016	0.004	-0.017	0.070
0.218	0.208	21	0.248	0.178	0.018	0.004	-0.010	0.064
0.232	0.225	7	0.237	0.194	0.015	0.006	-0.007	0.063
0.239	0.227	10	0.274	0.190	0.022	0.007	-0.012	0.066

Table 4.19 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 60.75 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.

4.4.7 Accuracy of RSD in Terms of Turbulence Intensity at 40.75 m Measurement Height

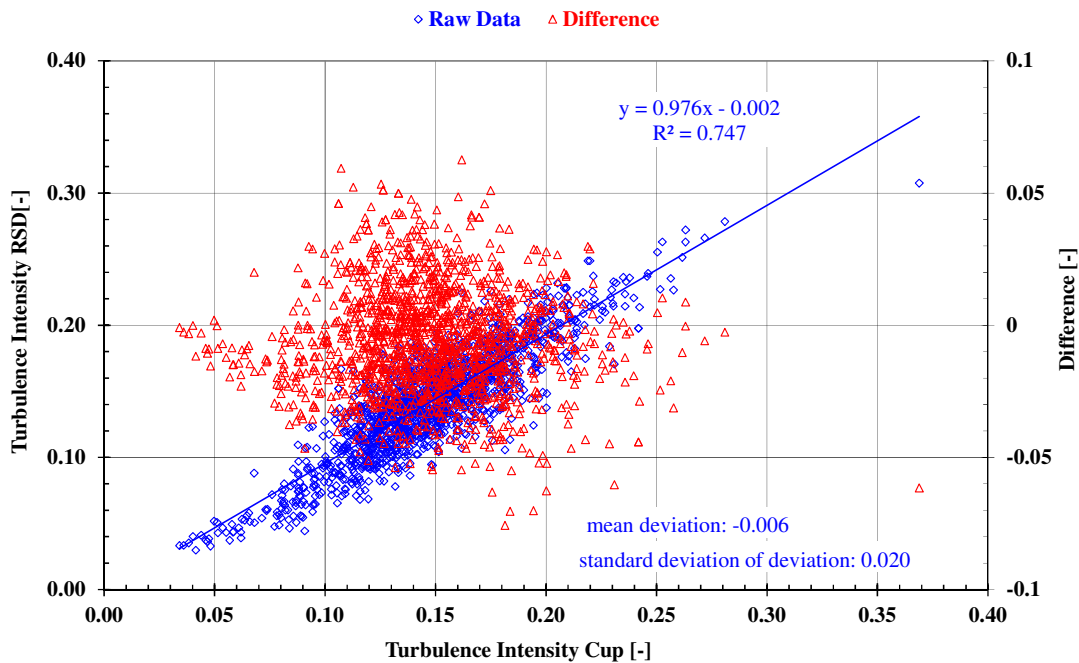


Figure 4.41 Scatter plot of Turbulence Intensity as measured by RSD against cup anemometer readings at 40.75 m height above ground and the deviation between both values in percent of the wind speed. Each point represents a 10-minute average.

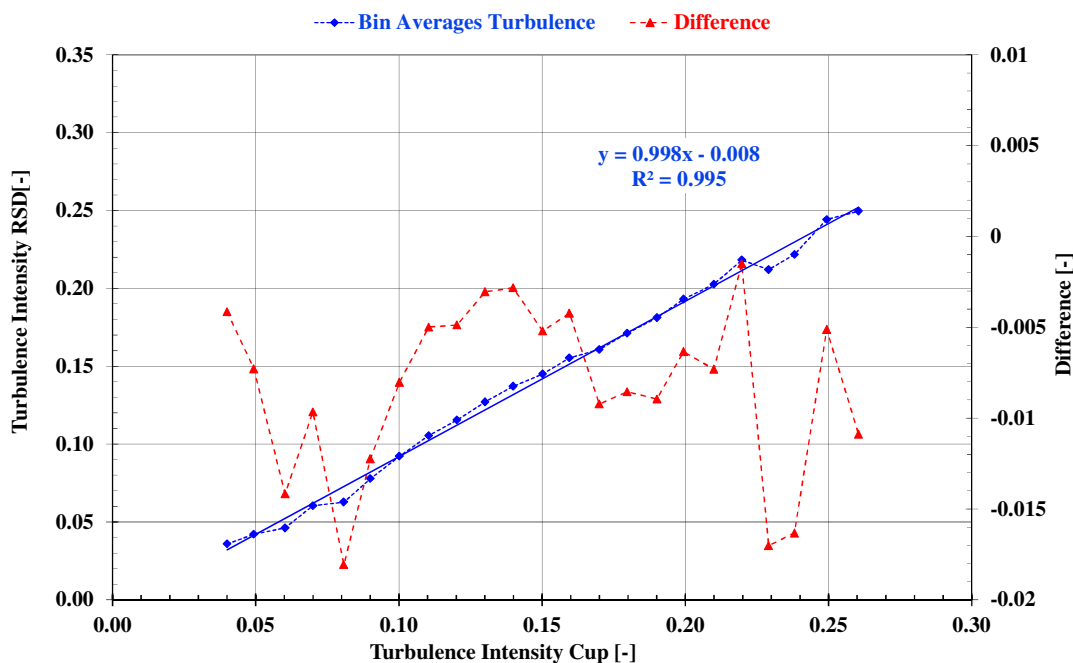


Figure 4.42 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 40.75 m height above ground. A positive sign of the shown deviation represents higher values measured by RSD.

TI (Reference)	TI (RSD)	number of data sets	TI (RSD) max	TI (RSD) min	TI (RSD) std	TI (RSD) std/sqrt(n)	TI (RSD) - TI (Reference)	uncertainty (k=2) TI (RSD)
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.040	0.036	5	0.041	0.030	0.005	0.002	-0.004	0.061
0.049	0.042	8	0.052	0.033	0.007	0.002	-0.007	0.062
0.060	0.046	11	0.056	0.037	0.006	0.002	-0.014	0.066
0.070	0.060	8	0.088	0.051	0.012	0.004	-0.010	0.064
0.081	0.063	21	0.080	0.046	0.010	0.002	-0.018	0.070
0.090	0.078	42	0.123	0.044	0.019	0.003	-0.012	0.065
0.100	0.092	38	0.133	0.065	0.017	0.003	-0.008	0.062
0.110	0.105	75	0.167	0.065	0.023	0.003	-0.005	0.061
0.120	0.115	137	0.166	0.068	0.020	0.002	-0.005	0.061
0.130	0.127	167	0.183	0.078	0.021	0.002	-0.003	0.060
0.140	0.137	180	0.187	0.086	0.020	0.002	-0.003	0.060
0.150	0.145	192	0.194	0.094	0.019	0.001	-0.005	0.061
0.160	0.155	143	0.224	0.107	0.020	0.002	-0.004	0.061
0.170	0.161	127	0.218	0.116	0.020	0.002	-0.009	0.063
0.180	0.171	113	0.226	0.106	0.022	0.002	-0.009	0.063
0.190	0.181	54	0.223	0.124	0.020	0.003	-0.009	0.063
0.199	0.193	44	0.228	0.138	0.022	0.003	-0.006	0.062
0.210	0.203	33	0.232	0.165	0.018	0.003	-0.007	0.062
0.220	0.218	13	0.249	0.175	0.020	0.006	-0.002	0.061
0.229	0.212	11	0.233	0.171	0.019	0.006	-0.017	0.070
0.238	0.222	8	0.236	0.198	0.013	0.005	-0.016	0.069
0.249	0.244	5	0.263	0.227	0.015	0.006	-0.005	0.062
0.260	0.250	5	0.272	0.226	0.019	0.008	-0.011	0.065

Table 4.20 Bin analysis of Turbulence Intensity measured by RSD against cup anemometer measurements at 40.75 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.

4.5 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 134.75 m , 100.75 m, 120.75 m, 81.75 m, 60.75 m and 40.75 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 very good with squared correlation coefficient of 0.999.
- The RSD shows value of mean deviation of -1.86° to 0.29° .
- Overall, the wind direction measurement of the RSD is considered as fine.

4.5.1 Accuracy of Wind Direction at 134.75 m Height

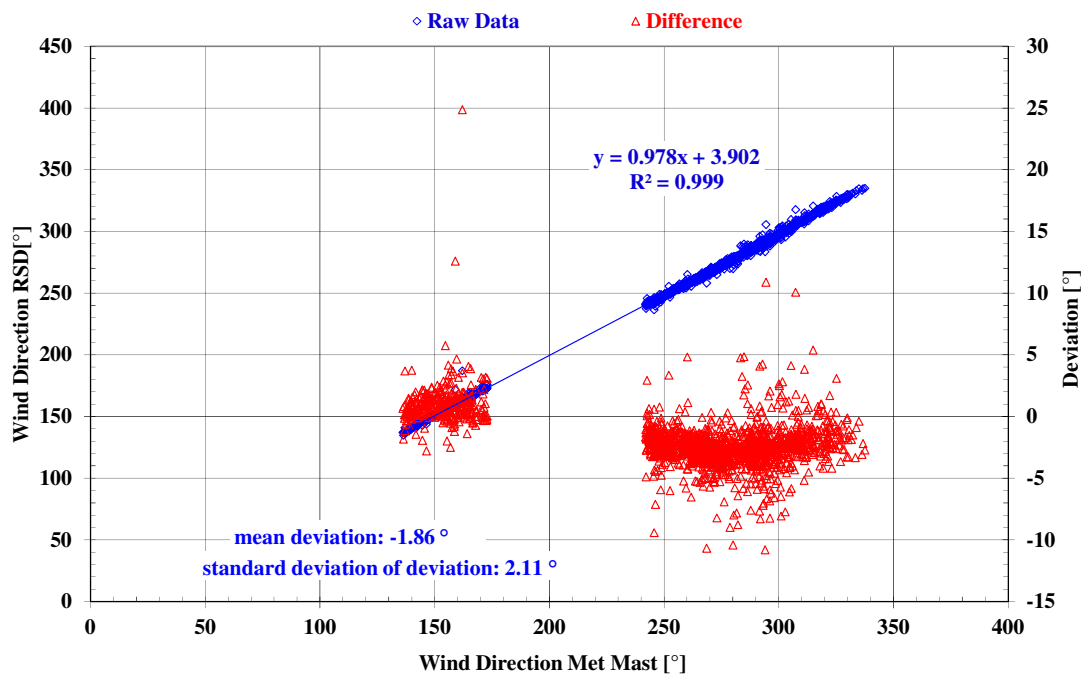


Figure 4.43: Scatter plot of wind direction as measured by RSD at 134.75 m height above ground against vane readings at 129 m measurement height.

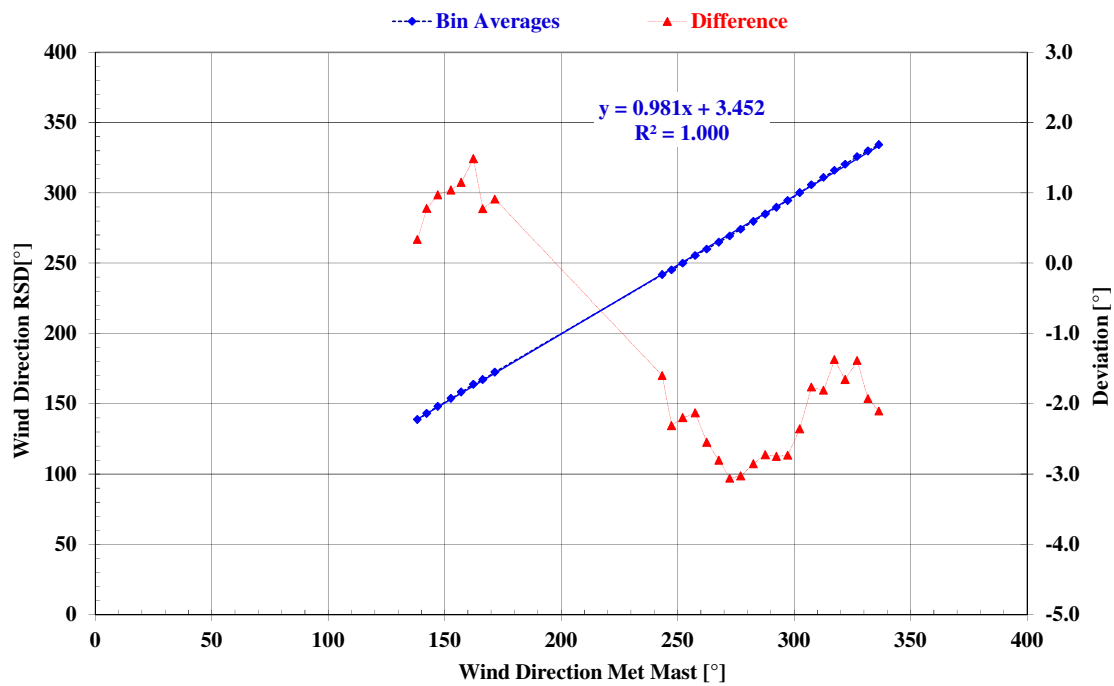


Figure 4.44: Bin analysis of wind direction as measured by RSD at 134.75 m height above ground against vane readings at 129 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
138.3	138.7	34	140.9	134.6	1.5	0.3	0.3	6.2	6.2
142.3	143.1	35	146.8	140.4	1.5	0.3	0.8	6.2	6.4
147.1	148.1	46	151.3	143.7	1.8	0.3	1.0	6.2	6.5
152.7	153.8	56	160.4	150.0	1.8	0.2	1.0	6.2	6.5
157.1	158.3	63	171.6	153.4	2.7	0.3	1.1	6.2	6.6
162.4	163.9	43	187.0	159.9	4.0	0.6	1.5	6.3	6.9
166.4	167.2	28	170.2	165.0	1.3	0.2	0.8	6.2	6.4
171.6	172.5	21	176.0	170.6	1.4	0.3	0.9	6.2	6.5
243.4	241.8	52	245.5	237.3	1.3	0.2	-1.6	6.2	7.0
247.5	245.1	110	248.9	236.3	2.0	0.2	-2.3	6.2	7.7
252.2	250.0	81	255.4	246.6	1.9	0.2	-2.2	6.2	7.6
257.6	255.5	63	259.6	252.4	1.6	0.2	-2.1	6.2	7.5
262.6	260.0	87	265.0	255.4	1.8	0.2	-2.5	6.2	8.0
267.7	264.9	161	268.5	257.9	1.7	0.1	-2.8	6.2	8.3
272.4	269.3	128	273.9	264.9	1.7	0.1	-3.1	6.2	8.7
277.2	274.1	99	279.2	269.4	2.0	0.2	-3.0	6.2	8.6
282.6	279.7	71	289.7	269.7	3.2	0.4	-2.9	6.2	8.4
287.7	285.0	112	289.0	280.3	1.8	0.2	-2.7	6.2	8.2
292.4	289.7	129	305.4	283.3	2.7	0.2	-2.7	6.2	8.3
297.3	294.6	86	300.5	288.0	2.2	0.2	-2.7	6.2	8.3
302.5	300.1	79	305.7	293.0	2.3	0.3	-2.4	6.2	7.8
307.5	305.7	73	317.5	299.7	2.4	0.3	-1.8	6.2	7.1
312.7	310.9	49	315.1	305.9	2.1	0.3	-1.8	6.2	7.2
317.3	316.0	31	320.4	312.6	2.1	0.4	-1.4	6.2	6.8
322.0	320.3	39	324.0	316.9	1.8	0.3	-1.7	6.2	7.0
327.1	325.7	21	329.8	322.4	2.0	0.4	-1.4	6.2	6.8
331.7	329.8	8	333.0	327.1	1.7	0.6	-1.9	6.2	7.3
336.4	334.3	4	334.9	333.2	0.7	0.4	-2.1	6.3	7.6

Table 4.21 Bin analysis of wind direction as measured by RSD at 134.75 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.

4.5.2 Accuracy of Wind Direction at 120.75 m Height

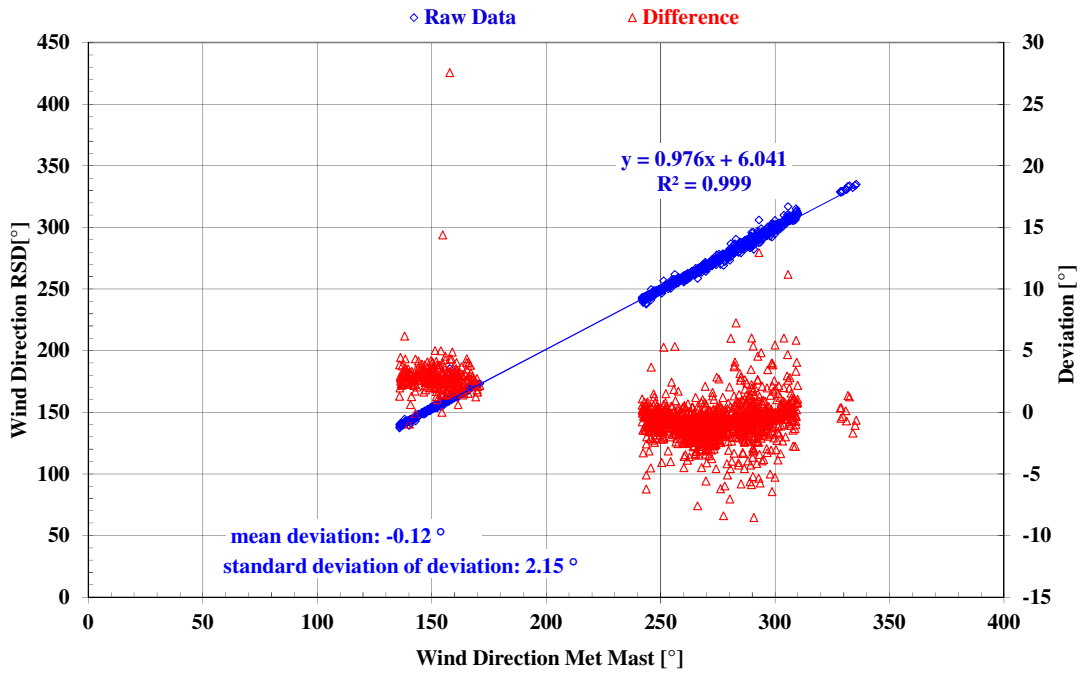


Figure 4.45: Scatter plot of wind direction as measured by RSD at 120.75 m height above ground against vane readings at 118.3 m measurement height.

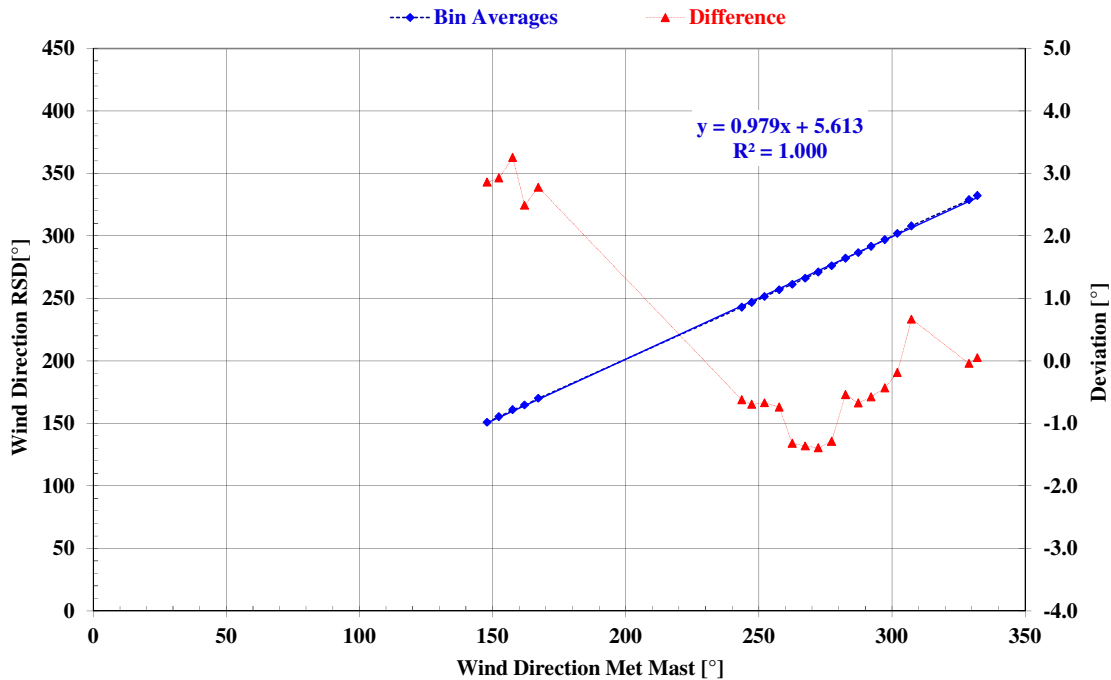


Figure 4.46: Bin analysis of wind direction as measured by RSD at 120.75 m height above ground against vane readings at 118.3 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
137.9	140.8	38	144.4	137.3	1.5	0.3	2.9	6.2	8.5
142.4	145.1	45	148.3	139.2	1.9	0.3	2.6	6.2	8.1
148.0	150.9	52	153.9	148.2	1.3	0.2	2.9	6.2	8.4
152.4	155.3	61	169.3	152.5	2.4	0.3	2.9	6.2	8.5
157.6	160.8	45	185.5	156.6	4.1	0.6	3.3	6.3	9.0
162.1	164.6	34	167.7	162.2	1.4	0.2	2.5	6.2	7.9
167.2	170.0	20	172.5	167.3	1.4	0.3	2.8	6.2	8.3
170.4	172.4	3	173.2	171.6	0.8	0.5	2.0	6.2	7.3
243.6	243.0	56	245.2	237.6	1.5	0.2	-0.6	6.2	6.3
247.3	246.6	98	250.2	241.2	1.7	0.2	-0.7	6.2	6.3
252.2	251.5	70	257.2	246.5	2.0	0.2	-0.7	6.2	6.3
257.7	256.9	66	261.6	253.6	1.6	0.2	-0.7	6.2	6.4
262.6	261.3	112	264.5	255.7	1.9	0.2	-1.3	6.2	6.7
267.5	266.1	163	271.6	258.6	1.9	0.1	-1.4	6.2	6.7
272.4	271.0	128	277.4	266.1	1.9	0.2	-1.4	6.2	6.8
277.4	276.1	77	280.3	269.1	2.0	0.2	-1.3	6.2	6.7
282.6	282.1	89	290.2	273.3	2.6	0.3	-0.5	6.2	6.3
287.4	286.7	126	295.8	279.4	2.2	0.2	-0.7	6.2	6.3
292.2	291.6	113	306.0	282.3	2.8	0.3	-0.6	6.2	6.3
297.4	297.0	78	302.8	291.3	2.4	0.3	-0.4	6.2	6.2
302.1	301.9	73	309.9	294.7	2.3	0.3	-0.2	6.2	6.2
307.3	308.0	61	316.9	304.8	2.4	0.3	0.7	6.2	6.3
329.0	328.9	4	329.3	328.3	0.5	0.2	0.0	6.2	6.2
332.1	332.2	5	333.8	330.6	1.4	0.6	0.1	6.3	6.3

Table 4.22 Bin analysis of wind direction as measured by RSD at 120.75 m height 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.

4.5.3 Accuracy of Wind Direction at 100.75 m Height

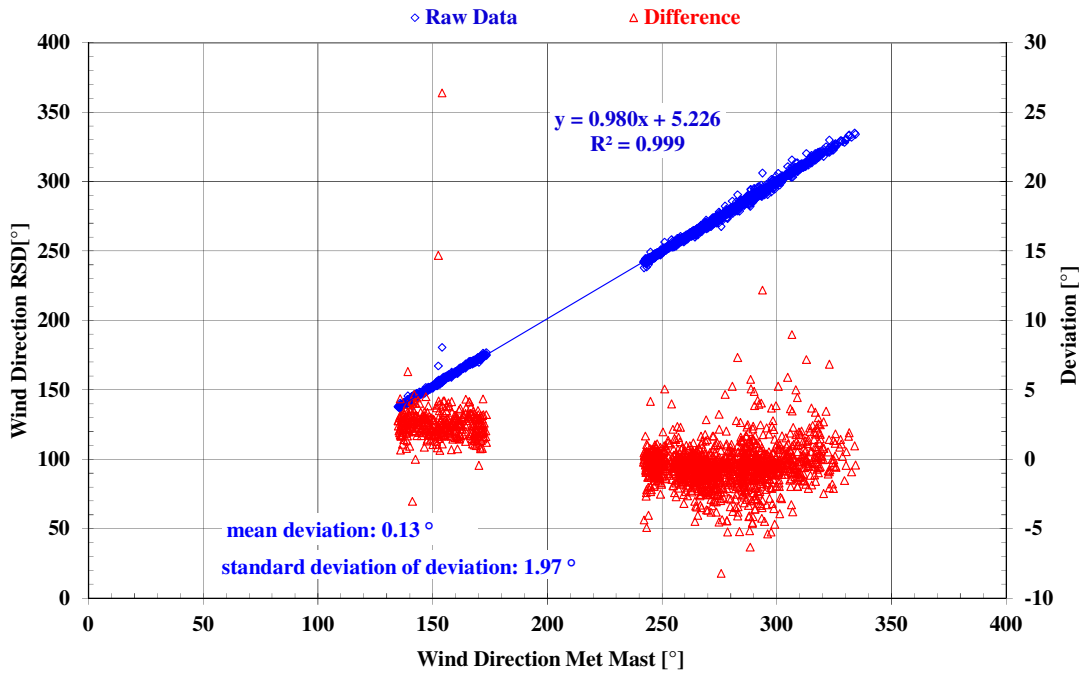


Figure 4.47: Scatter plot of wind direction as measured by RSD at 100.75 m height above ground against vane readings at 98.2 m measurement height.

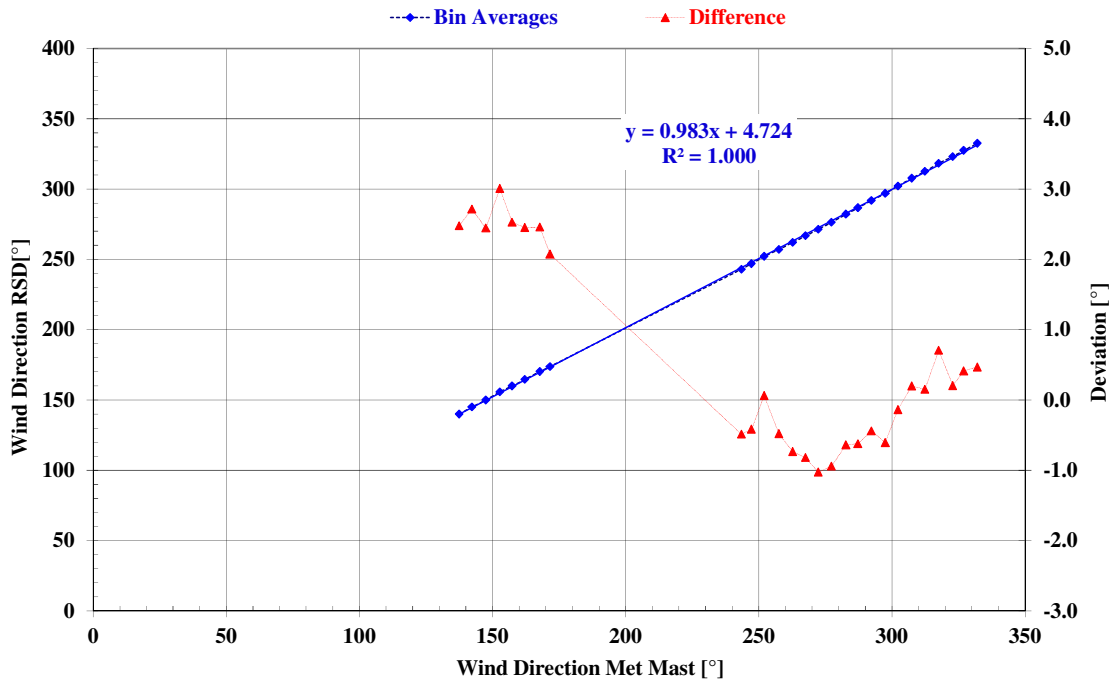


Figure 4.48: Bin analysis of wind direction as measured by RSD at 100.75 m height above ground against vane readings at 98.2 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
137.5	139.9	58	145.5	136.6	1.8	0.2	2.5	6.2	7.9
142.3	145.0	44	148.3	138.2	1.9	0.3	2.7	6.2	8.2
147.5	149.9	48	152.6	146.8	1.5	0.2	2.4	6.2	7.9
152.7	155.7	54	180.5	151.1	4.2	0.6	3.0	6.3	8.7
157.4	159.9	45	162.8	157.0	1.5	0.2	2.5	6.2	8.0
162.1	164.6	39	168.8	161.7	1.7	0.3	2.5	6.2	7.9
167.8	170.3	47	173.3	167.8	1.4	0.2	2.5	6.2	7.9
171.6	173.7	33	176.7	169.8	1.4	0.3	2.1	6.2	7.4
243.5	243.0	57	245.5	237.8	1.5	0.2	-0.5	6.2	6.3
247.3	246.9	112	250.2	242.8	1.6	0.2	-0.4	6.2	6.2
252.0	252.1	51	258.2	248.8	1.9	0.3	0.1	6.2	6.2
257.6	257.1	97	260.4	253.1	1.6	0.2	-0.5	6.2	6.3
262.8	262.0	110	265.0	258.1	1.6	0.2	-0.7	6.2	6.4
267.6	266.8	155	272.1	261.6	1.8	0.1	-0.8	6.2	6.4
272.4	271.3	118	278.1	266.3	1.9	0.2	-1.0	6.2	6.5
277.3	276.4	84	282.3	267.6	2.3	0.2	-0.9	6.2	6.5
282.8	282.2	79	290.3	277.0	2.4	0.3	-0.6	6.2	6.3
287.2	286.6	127	294.3	282.2	2.3	0.2	-0.6	6.2	6.3
292.3	291.9	108	306.0	286.9	2.5	0.2	-0.4	6.2	6.2
297.5	296.9	84	303.7	290.6	2.3	0.3	-0.6	6.2	6.3
302.3	302.1	56	310.7	297.5	2.4	0.3	-0.1	6.2	6.2
307.5	307.7	55	315.7	303.1	2.6	0.3	0.2	6.2	6.2
312.4	312.6	39	320.2	308.8	2.3	0.4	0.2	6.2	6.2
317.6	318.3	40	321.5	313.4	1.9	0.3	0.7	6.2	6.3
322.9	323.1	20	329.8	318.0	2.5	0.6	0.2	6.3	6.3
327.0	327.4	10	329.3	325.3	1.6	0.5	0.4	6.2	6.3
332.1	332.6	7	335.0	329.8	1.8	0.7	0.5	6.2	6.3

Table 4.23 Bin analysis of wind direction as measured by RSD at 100.75 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.

4.5.4 Accuracy of Wind Direction at 81.75 m Height

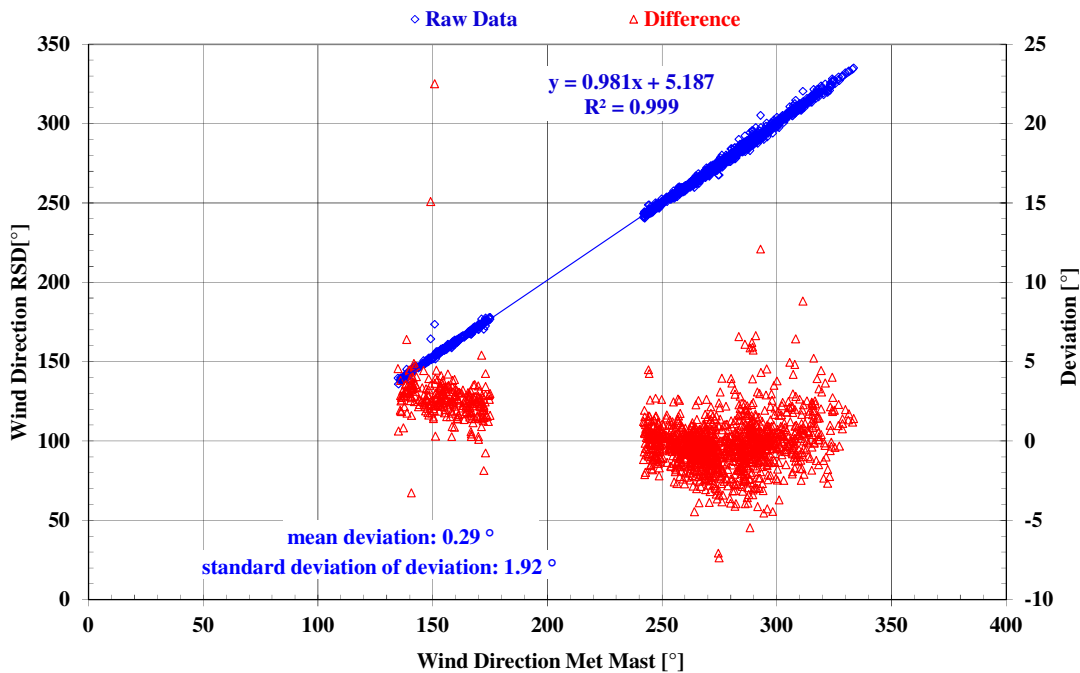


Figure 4.49: Scatter plot of wind direction as measured by RSD at 81.75 m height above ground against vane readings at 80.1 m measurement height.

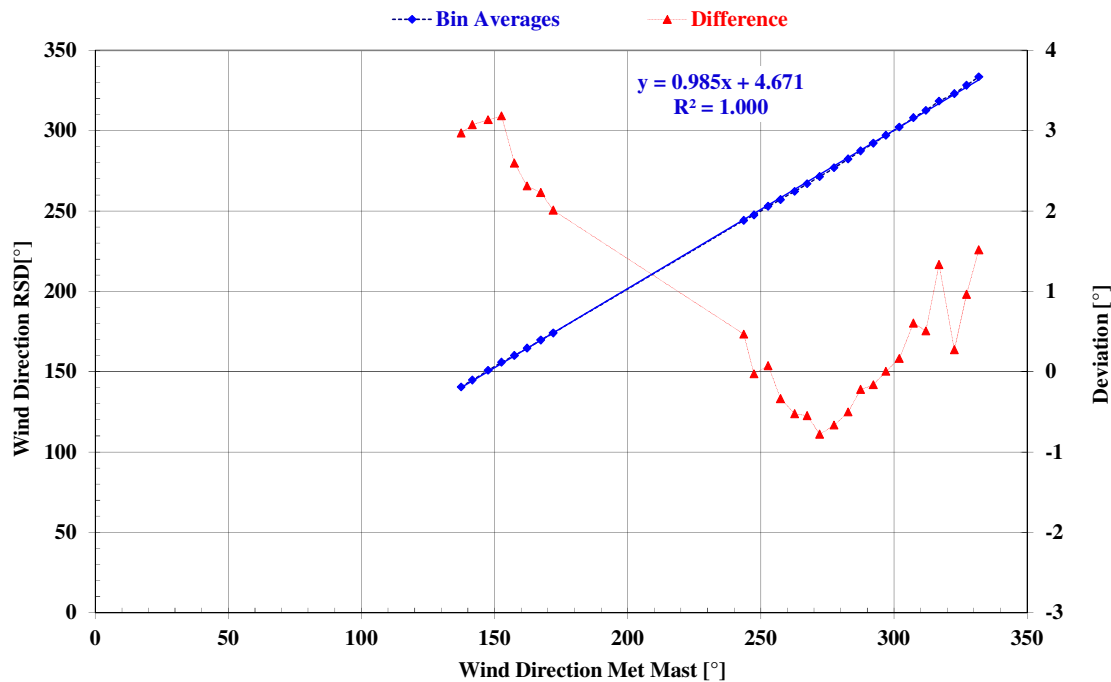


Figure 4.50: Bin analysis of wind direction as measured by RSD at 81.75 m height above ground against vane readings at 80.1 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
137.5	140.4	28	145.1	135.7	2.1	0.4	3.0	6.2	8.6
141.7	144.7	33	147.3	137.4	1.9	0.3	3.1	6.2	8.7
147.6	150.8	26	164.3	147.8	3.0	0.6	3.1	6.3	8.9
152.6	155.8	48	173.4	151.6	3.1	0.5	3.2	6.2	8.9
157.5	160.1	41	163.5	157.0	1.7	0.3	2.6	6.2	8.1
162.2	164.6	28	167.2	162.1	1.6	0.3	2.3	6.2	7.7
167.4	169.6	40	173.4	167.2	1.7	0.3	2.2	6.2	7.6
172.1	174.1	39	177.7	170.2	1.9	0.3	2.0	6.2	7.4
243.6	244.1	45	248.6	240.4	1.7	0.3	0.5	6.2	6.3
247.4	247.4	90	252.5	243.6	1.7	0.2	0.0	6.2	6.2
252.8	252.9	49	255.8	249.4	1.6	0.2	0.1	6.2	6.2
257.4	257.1	86	260.3	252.7	1.7	0.2	-0.3	6.2	6.2
262.7	262.2	121	267.1	258.0	1.7	0.2	-0.5	6.2	6.3
267.4	266.9	150	272.0	262.1	1.7	0.1	-0.5	6.2	6.3
272.1	271.3	126	277.2	266.8	1.9	0.2	-0.8	6.2	6.4
277.5	276.8	61	280.1	272.4	2.0	0.3	-0.7	6.2	6.3
282.8	282.3	89	290.1	277.6	2.2	0.2	-0.5	6.2	6.3
287.5	287.3	127	295.5	282.3	2.6	0.2	-0.2	6.2	6.2
292.3	292.1	104	305.1	287.2	2.3	0.2	-0.2	6.2	6.2
297.1	297.1	65	302.4	291.6	2.1	0.3	0.0	6.2	6.2
302.0	302.2	45	306.3	297.4	2.1	0.3	0.2	6.2	6.2
307.4	308.0	49	314.7	304.7	2.1	0.3	0.6	6.2	6.3
312.0	312.5	34	320.3	308.2	2.4	0.4	0.5	6.2	6.3
317.0	318.3	36	323.8	313.4	2.3	0.4	1.3	6.2	6.7
322.7	323.0	19	328.2	318.1	3.0	0.7	0.3	6.2	6.3
327.3	328.2	8	330.2	325.0	1.8	0.6	1.0	6.2	6.5
331.9	333.4	5	335.0	332.0	1.2	0.6	1.5	6.2	6.9

Table 4.24 Bin analysis of wind direction as measured by RSD at 81.75 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.

4.5.5 Accuracy of Wind Direction at 60.75 m Height

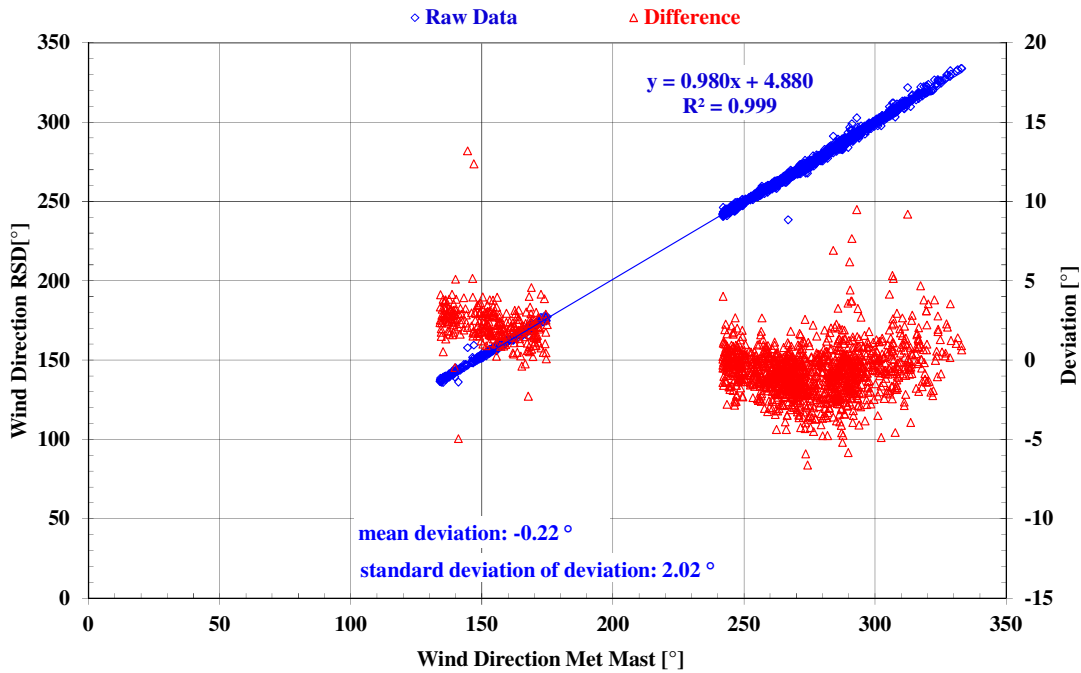


Figure 4.51: Scatter plot of wind direction as measured by RSD at 60.75 m height above ground against vane readings at 58.2 m measurement height.

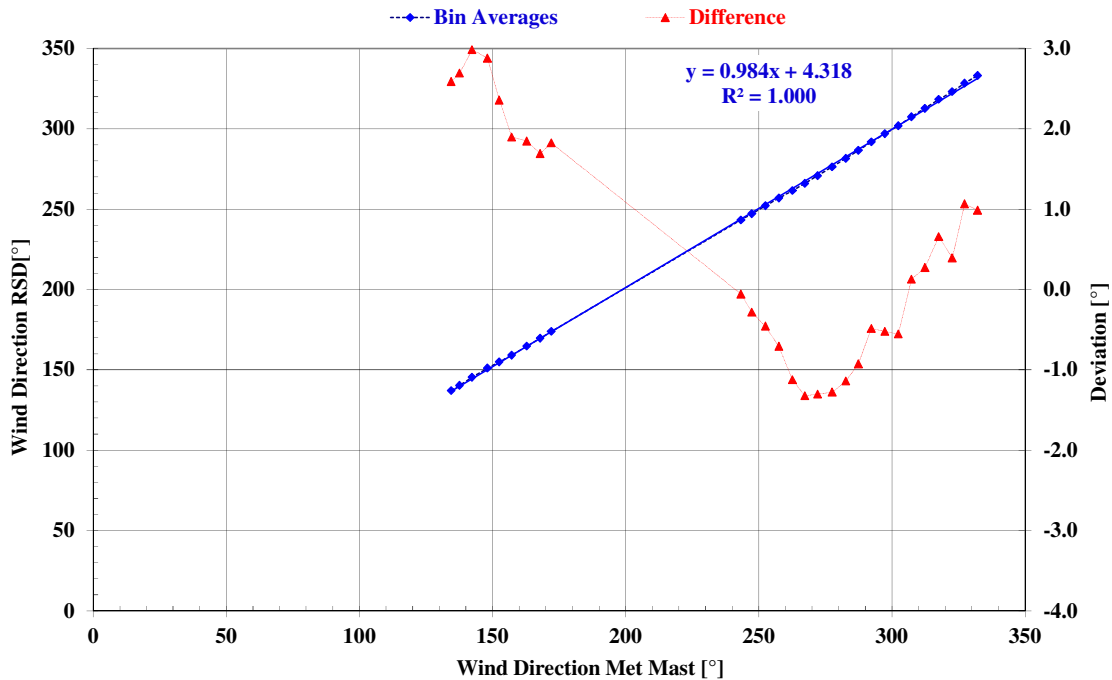


Figure 4.52: Bin analysis of wind direction as measured by RSD at 60.75 m height above ground against vane readings at 58.2 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
134.5	137.1	10	138.4	136.1	0.8	0.3	2.6	6.2	8.1
137.6	140.3	51	143.1	135.8	1.6	0.2	2.7	6.2	8.2
142.3	145.3	18	157.8	136.1	4.0	0.9	3.0	6.4	8.7
148.1	151.0	28	159.4	148.2	2.1	0.4	2.9	6.2	8.5
152.6	154.9	46	158.1	151.4	1.6	0.2	2.4	6.2	7.8
157.2	159.1	35	162.4	155.8	1.4	0.2	1.9	6.2	7.3
162.8	164.7	30	167.2	161.8	1.6	0.3	1.8	6.2	7.2
167.9	169.6	38	173.5	164.9	2.0	0.3	1.7	6.2	7.1
172.1	173.9	28	177.8	171.4	1.8	0.3	1.8	6.2	7.2
243.3	243.3	55	246.1	240.6	1.2	0.2	-0.1	6.2	6.2
247.4	247.1	93	251.3	243.6	1.6	0.2	-0.3	6.2	6.2
252.5	252.1	51	254.9	249.0	1.7	0.2	-0.5	6.2	6.2
257.6	256.8	91	260.1	252.7	1.9	0.2	-0.7	6.2	6.3
262.7	261.5	112	264.6	257.7	1.6	0.2	-1.1	6.2	6.6
267.3	266.0	149	269.7	238.3	2.8	0.2	-1.3	6.2	6.7
272.1	270.8	125	275.9	267.1	1.9	0.2	-1.3	6.2	6.7
277.6	276.3	62	280.0	271.8	2.1	0.3	-1.3	6.2	6.7
282.7	281.5	93	291.0	276.3	2.2	0.2	-1.1	6.2	6.6
287.4	286.5	132	293.3	281.5	2.1	0.2	-0.9	6.2	6.5
292.3	291.8	111	302.6	287.6	2.4	0.2	-0.5	6.2	6.3
297.4	296.9	47	300.5	292.4	1.9	0.3	-0.5	6.2	6.3
302.4	301.9	41	305.9	297.5	1.8	0.3	-0.6	6.2	6.3
307.3	307.5	50	312.1	303.1	2.3	0.3	0.1	6.2	6.2
312.4	312.7	36	321.7	308.3	2.4	0.4	0.3	6.2	6.2
317.6	318.3	33	322.7	313.9	2.2	0.4	0.7	6.2	6.3
322.7	323.1	15	326.8	318.6	2.9	0.8	0.4	6.3	6.3
327.3	328.4	9	332.3	324.3	2.4	0.8	1.1	6.2	6.6
332.2	333.2	4	333.9	332.0	0.8	0.4	1.0	6.2	6.5

Table 4.25 Bin analysis of wind direction as measured by RSD at 60.75 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.

4.5.6 Accuracy of Wind Direction at 40.75 m Height

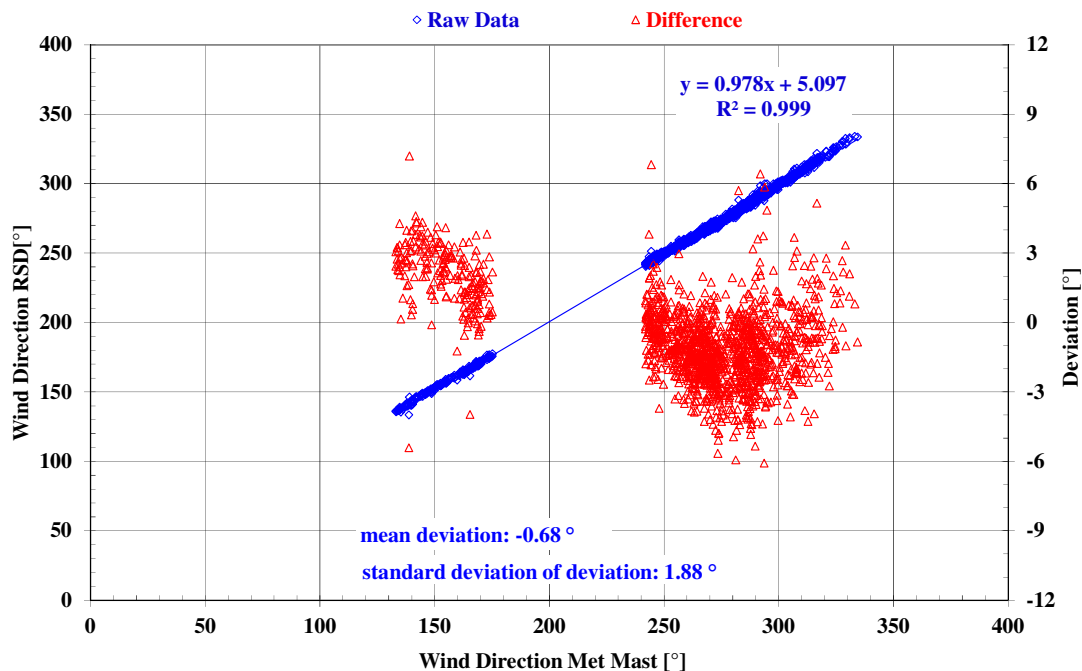


Figure 4.53: Scatter plot of wind direction as measured by RSD at 40.75 m height above ground against vane readings at 58.2 m measurement height.

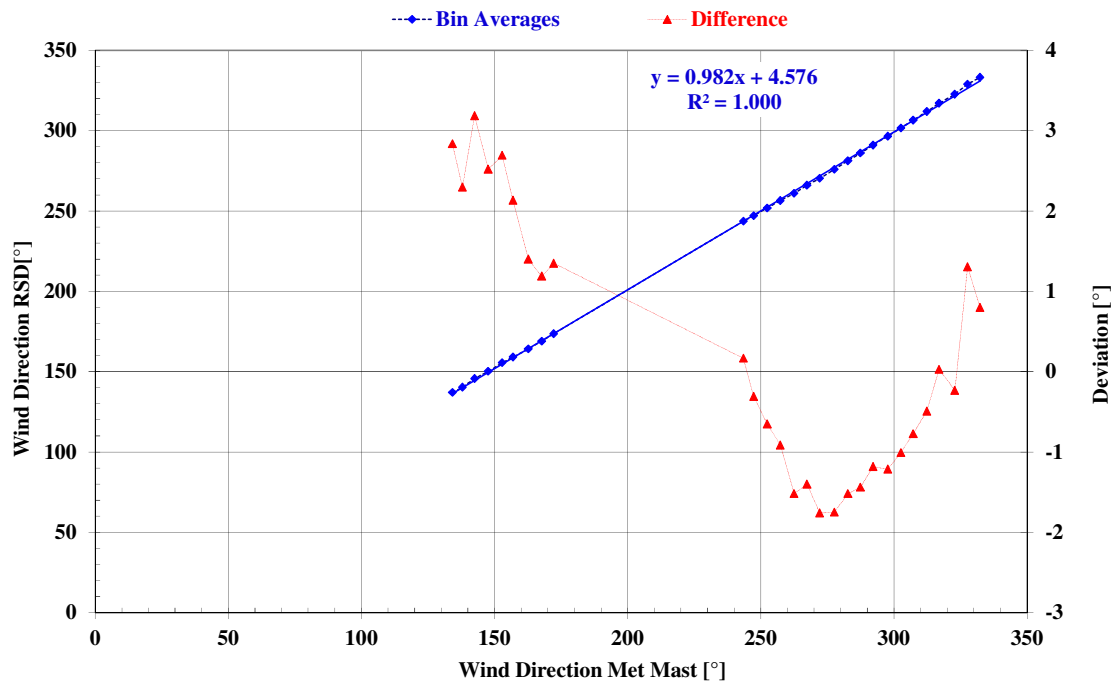


Figure 4.54: Bin analysis of wind direction as measured by RSD at 40.75 m height above ground against vane readings at 58.2 m measurement height.

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)
[°]	[°]	[-]	[°]	[°]	[°]	[°]	[°]	[°]	[°]
134.2	137.0	14	139.0	135.6	0.9	0.2	2.8	6.2	8.4
138.0	140.3	23	146.2	133.4	2.7	0.6	2.3	6.2	7.8
142.5	145.7	22	149.0	141.0	2.3	0.5	3.2	6.2	8.9
147.6	150.2	21	153.0	148.1	1.5	0.3	2.5	6.2	8.0
152.9	155.6	26	159.0	151.0	1.7	0.3	2.7	6.2	8.2
156.9	159.1	16	162.0	156.1	1.7	0.4	2.1	6.2	7.5
162.7	164.1	29	166.0	161.8	1.2	0.2	1.4	6.2	6.8
167.7	168.9	42	172.1	161.4	2.0	0.3	1.2	6.2	6.6
172.2	173.6	19	176.7	170.1	1.9	0.4	1.3	6.2	6.8
243.5	243.6	52	251.3	240.3	1.8	0.3	0.2	6.2	6.2
247.3	247.0	84	250.6	243.0	1.7	0.2	-0.3	6.2	6.2
252.4	251.8	50	254.9	249.2	1.4	0.2	-0.7	6.2	6.3
257.3	256.4	82	259.9	252.9	1.8	0.2	-0.9	6.2	6.4
262.6	261.0	107	265.2	257.4	1.6	0.2	-1.5	6.2	6.9
267.4	266.0	140	269.6	263.0	1.6	0.1	-1.4	6.2	6.8
272.1	270.4	118	274.5	265.9	1.7	0.2	-1.8	6.2	7.1
277.6	275.9	62	281.7	271.5	2.2	0.3	-1.7	6.2	7.1
282.7	281.2	100	288.2	275.4	2.1	0.2	-1.5	6.2	6.9
287.5	286.0	119	292.0	281.9	2.1	0.2	-1.4	6.2	6.8
292.2	291.0	98	299.7	286.4	2.4	0.2	-1.2	6.2	6.6
297.7	296.5	44	301.1	293.2	2.0	0.3	-1.2	6.2	6.6
302.6	301.6	36	305.2	298.3	1.5	0.3	-1.0	6.2	6.5
307.2	306.5	44	311.1	301.0	2.2	0.3	-0.8	6.2	6.4
312.4	311.9	39	316.6	307.7	2.4	0.4	-0.5	6.2	6.3
317.0	317.0	27	321.9	311.5	2.2	0.4	0.0	6.2	6.2
322.9	322.7	16	325.9	318.9	2.2	0.6	-0.2	6.2	6.2
327.7	329.0	8	332.4	326.6	1.9	0.7	1.3	6.3	6.8
332.4	333.1	4	334.0	331.9	0.9	0.4	0.8	6.3	6.5

Table 4.26 Bin analysis of wind direction as measured by RSD at 40.75 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.

5 Conclusions

The accuracy of the lidar of type Molas B300, serial number 4, 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, 40 m and 20 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 [1]. 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 lidar unit under the conditions during the test.

The main results of the calibration are:

- Depending on measurement height, the database consists of 1470 to 1810 10-minute datasets (1080 are required).
- The RSD shows a very good data availability of more than 99% for measurement heights up to 140m.
- The RSD shows an excellent correlation to cup anemometer measurements in terms of 10-minute averages of the horizontal wind speed component. At heights 135 m to 40 m measurement height the square of correlation coefficient about 0.99.
- For the tested measurement heights between 60 m to 135 m the RSD shows a marginal underestimation of the horizontal wind speed component with a mean deviation of -0.1 to -0.4% or -0.01 to -0.04 m/s.
- The resulting wind speed dependent uncertainties of the measurements of the horizontal wind speed component by the RSD are in the order of about 2% (expanded uncertainty $k=2$) in most wind speed bins for all measurement heights which is considered as good. The variation of the uncertainty reaches from 1.7% to 8.2% (expanded uncertainty $k=2$) for the different measurement heights and wind speed bins.
- The wind direction as measured by the RSD correlates very well to the wind direction as measured by vane on the met mast (squared correlation coefficient above 0.99).

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.

6 Literature

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- [3] MEASNET; Cup Anemometer Calibration Procedure, Version 2, October 2009
- [4] D-K-18020-01-00_DAKkS-DKD-RSV17005; Calibration Report, Deutsche WindGuard Consulting GmbH, 2016-03-16
- [5] RSV17003_Georgsfeld, Overview Report RSV, RSV17003.A1, Deutsche WindGuard Consulting 2017-05-02

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Height 40.8 m	Depen- dency [-]	shear exponent alpha 60m-40m		Turbulence Intensity I		Availability RSD		Wind direction		Air temperature T at 131 m		T difference 131m- 18m		air density		wind veer dir129m-dir39m		Flow Inclination angle	
		avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std	avg	std
Bin-No.	Windspeed [m/s]	[-]	[-]	[-]	[-]	[%]	[%]	[deg]	[deg]	[°C]	[°C]	[°C]	[°C]	[kg/m3]	[kg/m3]	[deg]	[deg]	[deg]	[deg]
9	4.129	0.302	0.202	0.136	0.040	100	0	234.342	64.802	5.254	2.711	-0.727	0.788	1.249	0.024	11.401	8.360	0.171	1.016
10	4.503	0.337	0.186	0.138	0.039	100	0	238.478	67.200	5.372	2.743	-0.540	0.998	1.245	0.024	11.790	8.357	0.434	1.218
11	4.984	0.321	0.187	0.131	0.037	100	0	258.404	53.318	5.394	2.669	-0.388	1.313	1.249	0.018	11.763	9.010	0.252	0.850
12	5.485	0.266	0.169	0.135	0.043	100	0	265.242	44.477	5.245	2.243	-0.611	1.135	1.248	0.015	9.071	8.094	0.159	1.343
13	5.977	0.161	0.113	0.151	0.029	100	0	273.000	32.437	5.509	1.693	-1.202	0.301	1.247	0.012	5.755	4.095	0.172	1.536
14	6.493	0.156	0.097	0.153	0.035	100	0	272.927	28.066	5.319	1.627	-1.272	0.240	1.245	0.010	5.277	3.547	0.072	1.151
15	6.986	0.153	0.084	0.153	0.029	100	0	270.354	27.537	5.331	1.937	-1.254	0.234	1.246	0.009	5.220	2.455	-0.043	1.130
16	7.500	0.155	0.086	0.157	0.029	100	0	276.388	30.793	4.774	1.906	-1.281	0.214	1.242	0.011	4.594	2.447	-0.117	1.018
17	8.030	0.161	0.068	0.154	0.030	100	0	276.315	22.786	5.528	2.311	-1.243	0.254	1.239	0.009	4.385	2.068	-0.238	0.767
18	8.499	0.150	0.064	0.163	0.026	100	0	278.101	25.848	5.734	2.339	-1.278	0.214	1.238	0.008	4.153	2.265	-0.146	0.764
19	9.041	0.148	0.061	0.163	0.031	100	0	275.695	22.820	5.755	2.641	-1.263	0.208	1.233	0.010	4.131	2.211	-0.225	0.829
20	9.486	0.160	0.054	0.161	0.034	100	0	273.041	22.851	5.712	2.276	-1.169	0.223	1.231	0.007	4.228	1.868	0.077	0.659
21	10.003	0.156	0.059	0.155	0.028	100	0	263.054	22.640	6.256	1.869	-1.182	0.201	1.228	0.006	3.690	1.831	-0.078	0.477
22	10.527	0.159	0.051	0.157	0.025	100	0	269.026	17.575	5.700	1.453	-1.187	0.221	1.225	0.006	3.916	1.328	-0.146	0.577
23	10.989	0.160	0.044	0.160	0.026	100	0	270.914	17.493	6.125	1.768	-1.173	0.183	1.224	0.005	3.760	1.104	-0.116	0.759
24	11.516	0.161	0.052	0.168	0.017	100	0	278.466	19.356	5.517	1.929	-1.230	0.182	1.218	0.006	4.152	1.883	0.113	0.611
25	11.959	0.160	0.044	0.180	0.036	100	0	275.551	24.540	6.135	2.102	-1.225	0.181	1.219	0.007	3.232	1.698	-0.122	0.725
26	12.490	0.156	0.027	0.146	0.017	100	0	256.971	11.058	6.888	1.841	-1.054	0.081	1.213	0.004	4.020	1.082	0.019	0.487
27	12.994	0.148	0.035	0.162	0.027	100	0	269.327	30.787	5.956	2.467	-1.114	0.106	1.214	0.007	4.155	1.402	-0.193	0.355
28	13.457	0.145	0.026	0.143	0.012	100	0	253.111	12.497	7.386	1.342	-1.095	0.095	1.212	0.003	3.567	0.931	-0.342	0.364
29	14.016	0.154	0.051	0.143	0.006	100	0	255.453	7.671	8.249	0.437	-1.081	0.061	1.210	0.003	3.600	1.371	-0.486	0.423
	Total	0.220	0.154	0.148	0.036	100	0	266.999	42.857	5.519	2.273	-0.942	0.813	1.241	0.017	7.326	6.692	0.092	1.075

Table 8.7: Average and standard deviation of measured ambient conditions in 40.75 m during test

Height 40.8 m	Depend ency [-]	shear exponent α 60m-40m		Turbulence Intensity I		Availability lidar		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 [%]	std [%]	avg [°C]	std [°C]	avg [°C]	std [°C]	avg [kg/m ³]	std [kg/m ³]	avg [deg]	std [deg]
27	134.171	0.564	0.080	0.087	0.014	100	0	7.278	3.663	0.683	0.367	1.224	0.032	21.800	3.399	0.353	0.542
28	137.965	0.363	0.258	0.130	0.026	100	0	7.665	2.505	-0.313	1.269	1.222	0.023	12.052	11.678	1.097	0.857
29	142.509	0.433	0.216	0.121	0.036	100	0	7.313	2.751	0.407	1.488	1.222	0.019	17.973	12.740	1.410	1.081
30	147.648	0.426	0.198	0.125	0.027	100	0	8.269	2.585	0.315	1.442	1.222	0.022	15.195	11.008	1.305	0.479
31	152.877	0.430	0.176	0.129	0.026	100	0	8.836	3.079	0.236	1.510	1.220	0.026	14.646	8.989	1.115	0.556
32	156.919	0.415	0.174	0.112	0.023	100	0	8.409	3.119	0.155	1.546	1.235	0.023	12.394	8.820	0.965	0.390
33	162.703	0.349	0.151	0.135	0.026	100	0	5.803	3.738	-0.295	1.644	1.238	0.024	12.676	9.348	0.855	0.631
34	167.726	0.333	0.160	0.140	0.028	100	0	4.679	3.699	-0.345	1.809	1.246	0.023	12.164	9.579	0.644	0.755
35	172.211	0.254	0.154	0.141	0.036	100	0	4.422	3.280	-0.874	1.143	1.245	0.025	6.284	7.837	0.533	0.828
49	243.460	0.218	0.134	0.131	0.041	100	0	5.247	2.105	-0.835	0.868	1.237	0.017	7.567	6.482	-0.779	0.586
50	247.321	0.187	0.107	0.130	0.035	100	0	5.307	2.331	-1.024	0.630	1.240	0.018	6.344	6.694	-0.510	0.692
51	252.412	0.211	0.109	0.123	0.034	100	0	6.061	2.085	-0.914	0.564	1.239	0.018	8.938	7.370	-0.555	0.540
52	257.348	0.208	0.126	0.129	0.034	100	0	6.116	2.352	-0.965	0.580	1.242	0.012	6.948	6.074	-0.236	0.707
53	262.552	0.195	0.117	0.134	0.024	100	0	5.978	1.896	-0.997	0.454	1.234	0.015	6.146	4.992	-0.054	0.543
54	267.374	0.182	0.081	0.153	0.028	100	0	5.784	1.708	-1.182	0.246	1.233	0.014	4.830	3.638	0.013	0.655
55	272.126	0.163	0.105	0.152	0.025	100	0	5.742	1.508	-1.213	0.338	1.237	0.015	4.915	4.862	0.027	0.753
56	277.632	0.173	0.111	0.152	0.024	100	0	5.543	1.634	-1.147	0.330	1.243	0.015	6.621	4.402	0.173	0.987
57	282.743	0.197	0.149	0.155	0.031	100	0	5.277	1.533	-1.054	0.446	1.248	0.012	7.880	4.402	0.289	1.011
58	287.467	0.212	0.173	0.148	0.030	100	0	5.308	1.414	-1.030	0.522	1.250	0.012	7.779	5.347	0.052	1.098
59	292.186	0.189	0.173	0.155	0.032	100	0	5.073	1.461	-1.084	0.484	1.253	0.010	6.837	5.319	0.225	1.643
60	297.709	0.186	0.160	0.160	0.029	100	0	4.660	1.779	-1.164	0.437	1.254	0.008	6.084	4.634	-0.135	1.535
61	302.642	0.169	0.120	0.172	0.031	100	0	4.342	1.964	-1.218	0.283	1.250	0.008	4.158	4.446	-0.020	1.261
62	307.239	0.182	0.095	0.185	0.026	100	0	4.101	1.648	-1.284	0.203	1.250	0.009	4.434	3.278	0.111	2.126
63	312.374	0.193	0.082	0.191	0.024	100	0	4.057	1.431	-1.225	0.204	1.251	0.007	4.856	3.197	-0.054	1.114
64	316.967	0.195	0.078	0.195	0.029	100	0	4.200	1.337	-1.340	0.108	1.250	0.008	5.233	2.531	-0.165	0.923
65	322.888	0.227	0.073	0.208	0.033	100	0	2.778	1.408	-1.260	0.105	1.241	0.013	3.681	1.048	-0.007	0.609
66	327.650	0.207	0.033	0.192	0.021	100	0	1.954	0.236	-1.214	0.033	1.231	0.009	4.125	1.826	-0.157	1.004
67	332.350	0.200	0.021	0.221	0.021	100	0	1.970	0.107	-1.206	0.031	1.226	0.001	3.800	1.023	-	-
Total		0.220	0.154	0.148	0.036	100	0	5.519	2.273	-0.942	0.813	1.241	0.017	7.326	6.692	0.092	1.075

Table 8.13 Average and standard deviation of measured ambient conditions in 40.75 m during test